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Use of Activated Carbon to Control Volatilization of Organic Contaminants from the Indiana Harbor Confined Disposal Facility

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and Paul R. Schroeder

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Abstract

Volatilization controls have been considered to meet limits on volatile emissions that may be imposed on dredging, disposal, and site management of an Indiana Harbor and Canal (IHC) Confined Disposal Facility (CDF). Carbon adsorption is a proven technology for removal and sequestration of organic compounds in water, but its application to control volatile emissions from dredging operations has not been thoroughly investigated. This study investigated the processes relevant to volatile emission control, including the forms of activated carbon to use, application rates, and application methods appropriate for IHC CDF.

Based on settling tests, a regenerated carbon, which can be used at about one-half the cost of virgin activated carbon, was selected for the study. The adsorption isotherm data showed that carbon adsorption was very effective for the removal of three- and higher-ring polynuclear aromatic hydrocarbons (PAHs) from water. Column settling tests showed that powdered activated carbon addition to dredged material slurries either enhanced settling or had no effect. Carbon treatment of dredged material slurry, dredged material ponded water, and exposed dredged material solids effectively reduced volatilization of lower molecular weight PAHs in laboratory studies. Carbon treatment appeared to have little effect on reducing volatilization of higher molecular weight PAHs and volatile organic compounds.

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Contents

Abstract.....	ii
Figures and Tables.....	v
Preface.....	ix
Unit Conversion Factors.....	x
1 Introduction.....	1
1.1 Indiana Harbor project background.....	1
1.2 IHC air emission issues	2
1.3 Study objectives and report scope	4
2 Sediment Collection and Characterization	6
2.1 Sediment collection.....	6
2.2 Sediment characterization	7
2.2.1 Chemical characteristics	7
2.2.2 Physical characteristics	17
3 Carbon Selection	19
4 Carbon Adsorption Isotherms	25
4.1 Introduction.....	25
4.2 Methods	26
4.2.1 Elutriate preparation and characterization	26
4.2.2 Adsorption isotherm procedure.....	27
4.3 Reduction of VOC and PAH dissolved concentrations	29
4.3.1 LMW PAHs	29
4.3.2 HMW PAHs.....	31
4.3.3 VOCs.....	33
4.4 PAH adsorption isotherms.....	33
4.5 VOC adsorption isotherms	42
4.6 Adsorption isotherm summary.....	44
5 Column Settling Tests.....	46
5.1 Background.....	46
5.2 Methods	46
5.3 Settling column results	49
5.3.1 Zone and compression settling.....	49
5.3.2 Flocculent settling.....	55
5.3.3 Column settling summary.....	60
6 Contaminant Volatilization Investigations	61
6.1 Introduction.....	61

6.2	Laboratory air emission experimental methods	61
6.2.1	Small flux chamber experiments.....	61
6.2.2	Large flux (resuspension) chamber tests	64
6.2.3	Wind tunnel tests	65
6.2.4	Chemical analytical methods for volatilization experiments	68
6.2.5	Experimental description summary	69
6.3	Laboratory volatilization test results	69
6.3.1	Small flux chamber with unamended sediment.....	69
6.3.2	Resuspension chamber volatilization results for unamended sediment.....	75
6.3.3	Small flux chamber experimental results for PAC-amended slurry.....	75
6.3.4	Small chamber results for PAC-amended supernatant (pond water)	81
6.3.5	Comparison of PAC treatment of slurry compared to ponded water	81
6.3.6	Small chamber results for PAC- and GAC-amended exposed sediment.....	83
6.3.7	Wind tunnel experimental results	86
7	Conclusions.....	91
	References.....	93
	Appendix A: Memorandum for Record -Sediment Sampling in Indiana Harbor	95
	Appendix B: Batch Activated Carbon Adsorption Data	98
	Appendix C: Column Settling Data	104
	Appendix D: Laboratory Volatilization Data	121
	Report Documentation Page	

Figures and Tables

Figures

Figure 1. Indiana Harbor 2005 sediment sampling area.	6
Figure 2. IHC Turning Basin sediment PAH concentrations (composite sample).	13
Figure 3. IHC Turning Basin sediment VOC concentrations (composite sample); acetone was below the detection limit (<20,000 µg/kg) and is not shown.....	14
Figure 4. IHC Turning Basin sediment grain size distribution	18
Figure 5. Carbon settling Test I – 3 minutes	22
Figure 6. Carbon settling Test I – 39 minutes	23
Figure 7. Carbon settling Test II – 60 minutes	23
Figure 8. Carbon settling Test II- 900 minutes	24
Figure 9. Percent reduction in LMW PAH concentration vs. PAC dosage	30
Figure 10. Percent reduction in LMW PAH concentration vs. GAC dosage	31
Figure 11. Percent reduction in HMW PAH concentration vs. PAC dosage	32
Figure 12. Percent reduction in HMW PAH concentration vs. GAC dosage	32
Figure 13. Percent reduction in VOC concentration vs. PAC dosage	34
Figure 14. Percent reduction in VOC concentration vs. GAC dosage	34
Figure 15. PAC-PAH isotherms	35
Figure 16. GAC-PAH isotherms	38
Figure 17. Langmuir equation for LMW PAHs (sum of NAPHTH, 2-MeNAPH, ACENAP, ACENAY, FLUORE, PHENAN, and ANTHRAC.	42
Figure 18. PAC-VOC isotherm plots.....	43
Figure 19. GAC-VOC isotherm plots.	44
Figure 20. Settling column	47
Figure 21. Conceptual sketch of zone and compression settling	47
Figure 22. Interface settling curve, 101.7 g/L slurry, no carbon.....	49
Figure 23. Zone settling curve, 101.7 g/L slurry, no carbon.....	50
Figure 24. Compression settling curve, 101.7 g/L slurry, no carbon	50
Figure 25. Interface settling curve, 101.9 g/L slurry, 1% PAC.	51
Figure 26. Zone settling curve, 101.9 g/L slurry, 1% PAC.....	51
Figure 27. Compression settling curve, 101.9 g/L slurry, 1% PAC	52
Figure 28. Interface settling curve, 76.8-g/L slurry, no carbon.	53
Figure 29. Zone settling curve, 76.8-g/L slurry, no carbon.....	53
Figure 30. Compression settling curve, 76.8-g/L slurry, no carbon.....	54
Figure 31. Interface settling curve, 78.6-g/L slurry, 5% carbon.	54
Figure 32. Zone settling curve, 78.6-g/L slurry, 5% PAC.....	55
Figure 33. Compression settling curve, 78.6-g/L slurry, 5% PAC.....	55

Figure 34. Flocculent settling curves for 102-g/L dredged material slurry, (a) no PAC, and (b) 1% PAC.....	56
Figure 35. Flocculent settling curves for 78-g/L dredged material slurry, (a) no PAC, and (b) 5% PAC.....	57
Figure 36. Suspended solids as a function of depth and time.....	58
Figure 37. Small laboratory flux chamber.	62
Figure 38. Small flux chamber laboratory schematic diagram.....	62
Figure 39. Large flux chamber.	65
Figure 40. Laboratory wind tunnel setup.....	66
Figure 41. Naphthalene, 1-methylnaphthalene, 2 methylnaphthalene, acenaphthylene, and acenaphthene flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).....	72
Figure 42. Fluorene, phenanthrene, anthracene, fluoranthene, and pyrene flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).....	73
Figure 43. Volatile organic compound flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).....	74
Figure 44. PAH flux observed in resuspension chamber experiments simulating unamended dredged material slurry after initial settling	76
Figure 45. Volatile organic flux observed in resuspension chamber experiments simulating unamended dredged material slurry after initial settling	77
Figure 46. PAH flux for PAC-amended dredged material slurry	78
Figure 47. Volatile organic compound flux for PAC-amended dredged material slurry	79
Figure 48. PAH emission reductions for air samples from ponded water with TSS concentrations of 100, 350, and 700 mg/L where dredged material slurry was amended with PAC at doses of 25, 50, and 100 mg/L	80
Figure 49. PAH flux for ponded water (filtered dredged material slurry) amended with PAC	82
Figure 50. Volatile organic compound flux for ponded water	83
Figure 51. PAH removal with PAC added to laboratory-simulated ponded water (filtered) compared to losses from unamended ponded water at 3 TSS concentrations.	84
Figure 52. Comparison of removal efficiencies for PAC amended dredged material slurry to PAC amended ponded water.....	85
Figure 53. PAH losses from unamended exposed sediment.....	86
Figure 54. PAH flux for exposed sediment comparing unamended to PAC- and GAC-amended sediment.....	87
Figure 55. Percent PAH removal for PAC/GAC amended exposed sediment compared to unamended exposed sediment.	88
Figure 56. Particulate losses from exposed dredged material at various wind speeds during wind tunnel experiments.	88
Figure 57. Characterization of PAH concentration in particle size fractions for wind tunnel sediment.	90

Tables

Table 1. Sediment chemical and physical methods of analysis.	8
Table 2. PAH CAS numbers and long and short names.	9
Table 3. PCB congener scientific names and IUPAC numbers. ¹	11
Table 4. PAH mass distributions (percent of total PAHs).	13
Table 5. PCB congener concentrations (standard error).	15
Table 6. TOC and oil and grease levels (standard error).	16
Table 7. IHC Turning Basin sediment physical properties.	17
Table 8. PAC responsive carbon suppliers.	19
Table 9. Carbon settling test results.	21
Table 10. Chemical analytical methods for water.	28
Table 11. Chemical analyses of sediment and elutriate for isotherm testing.	28
Table 12. Fitted isotherm parameters.	41
Table 13. Laboratory reporting limits (LRLs) and analyte methods.	69
Table 14. Volatilization experimental methods summary.	70
Table B1. PAC batch PAH concentrations (µg/L) and sediment concentration (mg/kg)	98
Table B2. GAC batch PAH concentrations (µg/L) and sediment concentration (mg/kg).	100
Table B3. PAC batch VOC concentrations (µg/L) and sediment concentration (µg/kg)	102
Table B4. GAC batch VOC concentrations (µg/L) and sediment concentration (µg/kg).	103
Table C1. Indiana Harbor and Canal (IHC) sediment physical characteristics.	104
Table C2. IHC initial total solids concentration of settling test slurry with no carbon	104
Table C3. IHC zone settling test data with no carbon data	105
Table C4. IHC compression settling test with no carbon data	106
Table C5. IHC flocculent settling test with no carbon TSS and turbidity data	107
Table C6. IHC flocculent settling test with no carbon smoothed TSS data for input into SETTLE	108
Table C7. IHC 15-day column settling test with initial total solids concentration of 76.8 g/L and no carbon—initial total solids.	108
Table C8. IHC zone settling test with no carbon data	109
Table C9. IHC compression settling test with no carbon data	110
Table C10. IHC flocculent settling test with no carbon tss and turbidity data	111
Table C11. IHC flocculent settling test with no carbon smoothed data for input to SETTLE.....	112
Table C12. IHC 15-day column settling test with initial total solids concentration of 101.9 g/L and 1 % carbon initial total solids.	112
Table C13. IHC zone settling test 101.9 g/L slurry with 1 % carbon.	113
Table C14. IHC compression settling test 101.9 g/L slurry with 1 % carbon data.	114
Table C15. IHC flocculent settling test 101.9 g/L slurry with 1 % carbon TSS and turbidity data.	115
Table C16. IHC flocculent settling test 101.9 g/L slurry with 1 % carbon smoothed data for input to SETTLE.....	116
Table C17. IHC 15-day column settling test with initial total solids concentration of 78.6 g/L and 5 % carbon—initial total solids.	116

Table C18. IHC zone settling test 78.6 g/L slurry with 5 % carbon data.	117
Table C19. IHC compression settling test 78.6 g/L slurry with 5 % carbon data.	118
Table C20. IHC flocculent settling test 78.6 g/L slurry with 5 % carbon TSS and turbidity data.....	119
Table C21. IHC flocculent settling test 78.6 g/L slurry with 5 % carbon smoothed data for input to SETTLE.....	120
Table D1. Laboratory data and flux calculations for unamended exposed sediment (PAHs – traps).	121
Table D2. Laboratory data and flux calculations for unamended exposed sediment (VOCs – traps).	121
Table D3. Laboratory data and flux calculations for PAC/GAC amended exposed sediment (PAHs – traps 1 of 2).	122
Table D4. Laboratory data and flux calculations for PAC/GAC amended exposed sediment (PAHs – traps 2 of 2).	122
Table D5. Laboratory data and flux calculations for unamended sediment slurry (PAHs – traps 1 of 2).	123
Table D6. Laboratory data and flux calculations for unamended sediment slurry (PAHs – traps 2 of 2).	123
Table D7. Laboratory data and flux calculations for unamended sediment slurry (VOCs – traps).	124
Table D8. Laboratory data for unamended sediment slurry (PAHs – water).	125
Table D9. Laboratory data for unamended sediment slurry (VOCs – water).	125
Table D10. Laboratory data and flux calculations for PAC amended sediment slurry (PAHs – traps).	126
Table D11. Laboratory data and flux calculations for PAC-amended sediment slurry (VOCs – traps).	126
Table D12. Laboratory data for PAC-amended sediment slurry (PAHs – water).	127
Table D13. Laboratory data for PAC-amended sediment slurry (VOCs – water).	127
Table D14. Laboratory data and flux calculations for additional test (PAC-amended sediment slurry) (PAHs – traps).	128
Table D15. Laboratory data and flux calculations for additional test (PAC-amended sediment slurry) (VOCs – traps).	129
Table D16. Laboratory data for additional test (PAC-amended sediment slurry) (PAHs – water).	129
Table D17. Laboratory data for additional test (PAC-amended sediment slurry) (VOCs - water).	130
Table D18. Laboratory data and flux calculations for resuspension chamber test (PAHs – traps).	130
Table D19. Laboratory data and flux calculations for resuspension chamber test (VOCs – traps).	131
Table D20. Laboratory data and flux calculations for resuspension chamber test (PAHs – water).	131
Table D21. Laboratory data and flux calculations for resuspension chamber test (VOCs – water).	132
Table D22. Laboratory data for dust and sediment collected from wind tunnel experiments (PAHs).	132
Table D23. Laboratory data for particulate losses from wind tunnel experiments.	133

Preface

This report presents the results of sediment characterization, carbon adsorption isotherms, column settling tests, and volatilization experiments performed to demonstrate the effectiveness of activated carbon in reducing volatile emissions from dredged material from the Indiana Harbor and Canal, East Chicago, Indiana. The Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC) at the Waterways Experiment Station (WES) conducted this work. Funding for ERDC was provided by U.S. Army Engineer District, Chicago and the U.S. Environmental Protection Agency Great Lakes National Program Office (GLNPO). The Chicago District project manager for this effort is Le T. Thai. The GLNPO project officer for this study is Scott Cieniawski.

The report was prepared by Dr. Tommy E. Myers, Cynthia B. Price, Daniel E. Averett, and Dr. Paul R. Schroeder, Environmental Processes and Engineering Division (EPED), EL. Cheryl M. Lloyd assisted with tabular and graphical presentation of data and report format. Richard Hudson assisted in conducting the column settling tests. Susan Bailey and Damarys Acevedo-Acevedo provided technical review for the report.

This study was conducted under the direct supervision of Warren P. Lorentz, Chief, EPED, and under the general supervision of Dr. Beth C. Fleming, Director, EL.

COL Kevin J. Wilson was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles per hour	0.44704	meters per second

1 Introduction

1.1 Indiana Harbor project background

Indiana Harbor and Canal (IHC) is an authorized Federal navigation project located in East Chicago, Indiana. Sediments in the IHC are contaminated with metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and volatile organic compounds (VOCs), and have been determined to be unsuitable for open-water disposal, unconfined upland disposal, and beneficial use. Dredging of the IHC has been deferred since 1972 while a technically and economically feasible and environmentally acceptable management plan was developed. The results of environmental studies and technical evaluations conducted in the course of developing a management plan for Indiana Harbor sediments are summarized in the Comprehensive Management Plan (CMP) (U.S. Army Corps of Engineers (USACE), Chicago 1999), the Design Documentation Report (DDR) (USACE, Chicago 2000), and the Disposal Alternatives for PCB-Contaminated Sediments from Indiana Harbor, Indiana (Environmental Laboratory 1987a and 1987b).

The DDR documents a confined disposal facility (CDF) design prepared for the selected plan from the CMP. Based on the evaluations presented in the IHC Dredging and Disposal Alternatives Analysis (Estes et al. 2003) and previous studies, mechanical dredging and disposal has been identified as the preferred dredging method for Indiana Harbor. However, operational constraints regarding barge access, ability of the dredged material to support truck traffic, spreading of dredged material in the CDF, truck access, and potential for increased loss of fugitive dust have led to evaluation of hydraulic placement options for the mechanically dredged material. The least costly placement option includes recirculation of the carrier water from the sediment storage cells and the use and long-term storage of runoff water as the carrier water to reduce water treatment costs, but this option increases the concern for volatile losses due to the long-term storage of contaminated water and potentially higher contaminant concentrations in the water.

A projected dredging rate was established based on documented sediment depths and projected accumulation over a period of 30 years, and a design was developed for the disposal site. The proposed CDF is sited on about 140

acres above a pool of contaminated groundwater that has high concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as other volatiles and semi-volatiles. At the time of this study, the CDF was proposed to be subdivided into cells for about 90 acres of sediment storage and dewatering, and potentially about 10 acres of retention/equalization for treatment of dredging operations water and groundwater or storage of runoff water and groundwater for carrier water supply. The projected disposal scenario for dredged material placement and storage specifies a CDF with three primary storage cells, a fourth cell for placement of Toxic Substances Control Act (TSCA) material, and an equalization/water storage basin. Presently, a two-cell design is being implemented.

At the time of this study, the proposed dredging operation was as described below; however, the operating plan does not include dewatering and desiccation or use of an equalization basin. Instead, water will be ponded between dredging seasons. Nevertheless, the laboratory experiments and study results described in this report provide new information on estimating contaminant volatilization from the CDF and evaluating the potential efficacy of activated carbon treatment if volatile losses were to become a problem.

A typical dredging project will take about 60 days to place about 230,000 yd³ of dredged material per year in the CDF. In the 10 days following dredged material placement, the ponded water will be transferred to the equalization basin to await treatment. The cells will be allowed to consolidate and desiccate for 2 years between disposal operations. Surface runoff and pore water produced by consolidation will be frequently pumped to and stored in the equalization basin to promote the dewatering. The dredging operations water and site groundwater will only be treated seasonally in a 4-month period following the dredging. During the rest of the year, the groundwater and runoff will be stored in the equalization basin until the next dredging operation, when it will be used as carrier water for dredged material placement in the hydraulic offloading process.

1.2 IHC air emission issues

Concern has been expressed by the public regarding the potential loss of volatiles and particulates from the CDF. An air risk assessment is being performed by the U.S. Environmental Protection Agency (USEPA) to determine limits on volatile emissions from the IHC CDF. The main volatile contaminants in the sediment (listed in order of decreasing magnitude of

anticipated emissions) are naphthalene, toluene, phenanthrene, benzene, acenaphthene, and acenaphthylene. The principal constituents in the groundwater contributing to volatilization are total xylenes, ethylbenzene, toluene, benzene, 2-methylnaphthalene, and acenaphthene.

Volatilization controls may be required to meet the limits on volatile emissions that will be imposed on dredging, disposal, and site management of the IHC CDF. Little or no research has been performed on controls for volatile emissions during dredging and dredged material disposal operations. Carbon adsorption is a proven technology for removal and sequestration of organic compounds in water, but its application to control of volatile emissions from dredging operations has not been thoroughly investigated. U.S. Steel has used activated carbon during hydraulic dredging of the Grand Calumet River as a measure to control volatile emissions from their CDF. However, data from this project that would enable generalizing this experience to other sites or projects were not available at the time of this study. Currently, insufficient information is available to formulate recommendations about activated carbon application rates for control of volatile emissions from a CDF.

Volatile emissions occur mainly from two locales: ponded water from dewatering dredged material or runoff from precipitation and exposed, dewatered, desiccating dredged material. Two approaches exist to control emissions from ponded water. The first method would apply activated carbon to the ponded water by spraying or injecting a slurry of activated carbon and water to reduce dissolved concentrations of VOCs and semi-volatiles and therefore the emissions. Spraying uniformly may be difficult for larger CDFs; however, wind-induced circulation can provide the distribution of the activated carbon throughout the ponded water. Alternatively, pumps can be used to recirculate CDF water by withdrawing clarified water from the CDF on the end opposite the slurry discharge and injecting carbon into the pump discharge pipe near the slurry discharge. The addition of activated carbon would be needed throughout the dredging and initial dewatering operation. Addition of activated carbon to the runoff storage basin may also be needed to maintain reduced contaminant concentrations in the periods between disposal projects. The second method would apply activated carbon to the influent dredged material slurry to reduce the concentration of VOCs and semi-volatiles in the carrier water, thereby reducing the concentration of these compounds in the ponded water generated during dewatering. The dosage required for the second method

would likely be much larger than required for the first method but the second method may provide benefits that are more comprehensive. The impacts of applying the first method to the dredged material storage cell during dredging operations are unknown in regards to controlling emissions from the runoff or the exposed sediment after dewatering; however, if high dosages of powdered activated carbon (PAC) are used and the PAC settles well, emissions from runoff and exposed sediment are likely to be somewhat controlled. The second method would be expected to control volatile emissions from both runoff and exposed dredged material without additional application of activated carbon.

Research was therefore needed to develop a sufficient understanding of the processes relevant to volatile emission control to base recommendations about the forms of activated carbon to use, application rates, and application methods appropriate for IHC CDF. Consideration must be given to the effects of activated carbon addition on dewatering, sedimentation, consolidation, storage requirements, and dust control.

1.3 Study objectives and report scope

The strong adsorption properties of activated carbon make this material a promising treatment for reducing contaminant volatile flux during dredged material disposal. The overall objective of this study is to demonstrate the effectiveness of activated carbon for reducing volatile emissions. The scope of this study does not include design of an activated carbon tower for effluent treatment, long-term effects of activated carbon amendment on biological growth in a CDF, or risk reduction that might be associated with activated carbon amendment of dredged material disposed in a CDF. The general study objectives are as follows:

- Develop a sufficient understanding of the processes that control volatile emission rates to make recommendations regarding PAC efficacy for reducing volatile emissions and application rates for ponded water in the CDF;
- Using physical models, determine volatile emission rates from exposed dewatered dredged material as a function of application rate and type of activated carbon;
- Investigate the role of settled dredged material on emissions from ponded water in the CDF;
- Evaluate the potential for particulate emissions of VOCs and PAHs from exposed dewatered dredged material with PAC amendment; and

- Determine the settling and consolidation behavior of PAC-amended dredged material and evaluate implications thereof on CDF design for retention time and storage volume.

This report describes testing and test results in support of the objectives listed above.

2 Sediment Collection and Characterization

2.1 Sediment collection

Sediment samples were collected by U.S. Army Corps of Engineers, Chicago (CELRC) in June 2005. The sampling effort is described in Appendix A and briefly here. The area sampled is located in the southern corner of the main turning basin, adjacent to the Indiana Harbor entrance (Figure 1). This area has been historically identified as having the potential to contain concentrations of organic compounds at levels higher than surrounding portions of the Indiana Harbor and Canal vicinity. The CELRC selected this site for sampling based on years of sediment sampling in Indiana Harbor. Since this is not a site investigation study, but rather a volatilization process investigation and analysis study, the exact sampling location is not particularly important. What is important is that the sediment collected be sufficiently contaminated to provide reliable numbers on volatile emissions. The volatile process understanding obtained will be generally applicable to all levels of contamination in Indiana Harbor.



Figure 1. Indiana Harbor 2005 sediment sampling area.

A Vibracore deployed from the USEPA Research Vessel (R/V) Mudpuppy was used to collect sediment samples. Sediment cores were placed in 5-gallon plastic buckets for transport to the U.S. Army Engineer Research and Development Center (ERDC). Buckets were filled to minimize head-space, capped with a rubber-sealed lid, and hammered shut in order to minimize volatile losses. At the end of each sampling day, sample buckets were transported to a cold storage warehouse, where they were kept at a temperature of 1.7 – 4.4°C (35-40°F). A total of 44 buckets were shipped to ERDC via a temperature-controlled truck. Thirty-one were assigned to this project.

2.2 Sediment characterization

Vigorous mixing of a large volume of sediment to reduce physical and chemical heterogeneity could result in significant losses of volatile and semi-volatile organics. The entire allotment of 31 buckets of sediment was therefore not mixed prior to experimentation. Each portion of sediment used in the experimentation was mixed and characterized in triplicate for the chemical parameters appropriate for each experiment. For purposes of general characterization, a grab sample was collected from 15 buckets and mixed together into one composite sample for chemical and physical characterization. This composite sample was homogenized prior to analysis. Three replicates were taken of the homogenized composite sample for chemical analyses and a single sample was used for physical characterization (grain size distribution, Atterberg limits, specific gravity, and water content). The samples for chemical analysis were analyzed for volatile (acetone, methylene chloride, xylenes, benzene, ethylbenzene, toluene) and semi-volatile organics (17 priority pollutant PAHs), PCBs, total organic carbon (TOC), and oil and grease.

2.2.1 Chemical characteristics

2.2.1.1 Chemical methods and nomenclature

Approved USEPA methods were used for chemical analyses. PAHs (17 priority pollutant PAHs) were extracted from sediment by USEPA SW-846 Method 3545 and analyzed by gas chromatography/mass spectrometry (GC/MS) as provided in USEPA SW-846 Method 8270C. VOCs were extracted from sediment using closed-system purge-and-trap as provided in USEPA SW-846 Method 8260B. TOC was analyzed as provided in USEPA SW-846 Method 9060. Sediment was extracted for PCBs (PCB Aroclors and

56 individual PCB congeners) as provided in USEPA SW-846 Method 3545 and analyzed using USEPA SW-846 Method 8082. Oil and grease in sediment was analyzed by USEPA SW-846 Method 9091B. Methods of analysis and lower reporting limits for sediment are listed in Table 1. The data tables and graphs that follow use Chemical Abstract Service (CAS) numbers and short names to identify specific PAHs and VOCs and IUPAC (International Union of Pure and Applied Chemists) numbers to identify PCBs in order to reduce clutter in subsequent tables and graphs. Table 2 lists CAS numbers for PAHs and VOCs along with PAH long and short names for reference. Table 3 lists PCB congener scientific names and IUPAC numbers.

2.2.1.2 PAHs and VOCs

Figure 2 shows mean PAH concentrations in the mixed-composite sediment sample. Error bars in Figure 2 are standard errors of the mean.

Naphthalene is the predominant PAH in the sediment at a concentration of 1457 mg/kg. Phenanthrene (708 mg/kg), fluoranthene (447 mg/kg), and pyrene (424 mg/kg) are also present in significant amounts. The total PAH mass concentration was 4829 mg/kg. These results are similar to the results of sampling the Federal channel in 1987 (Environmental Laboratory 1987a), which showed a total PAH concentration of 3229 mg/kg. Naphthalene was 2000 mg/kg in 1987; phenanthrene was 200 mg/kg; fluoranthene was 150 mg/kg; and pyrene was 140 mg/kg. Table 4 compares the percent mass distribution of PAHs in the 1987 Federal Channel sediment and the 2005 Turning Basin sediment.

Table 1. Sediment chemical and physical methods of analysis.

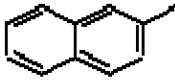
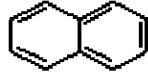

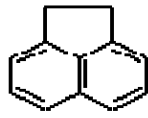
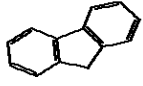
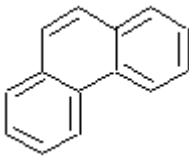
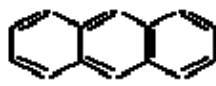
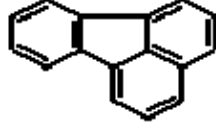
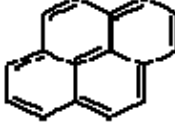
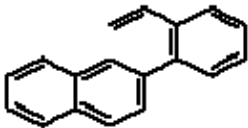
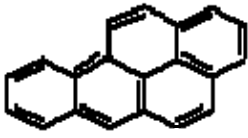
Analyte	Extraction method	Quantitation method ¹	LRL ²
VOCs ³	5035A	8260B	500 µg/kg
PAHs	3545	8270C	170 µg/kg
PCBs	3545	8082	10 µg/kg
Oil & Grease	9071B	9071B	33 mg/kg
TOC	Not applicable	9060	0.25 g/kg

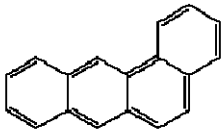
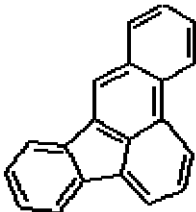
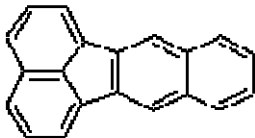
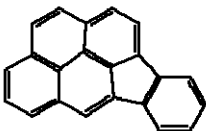
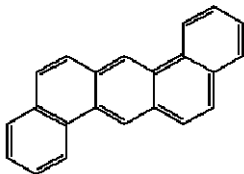
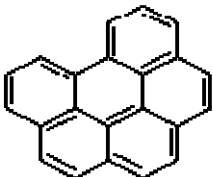
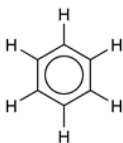
¹ Method numbers refer to SW-846 (USEPA 1996).


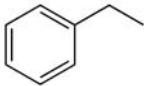
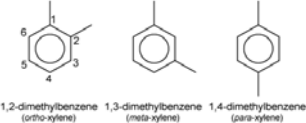
² LRL: The laboratory reporting limit (LRL) is the lowest analyte concentration that can be accurately measured and reported, as opposed to simply detected. LRLs for individual parameters are set at three to five times the determined method detection limit. The above LRLs are based on 100% solids. Wet sediment has a proportionally higher LRL.

³ Except for acetone, which is 10,000 µg/kg.

Table 2. PAH CAS numbers and long and short names.

Structure	CAS number	Long	Short
	91-57-6	2-Methylnaphthalene MW: 142.20	2MeNAPH
	91-20-3	Naphthalene MW: 128.18	NAPHTH
	208-96-8	Acenaphthylene MW: 152.20	ACENAY
	83-32-9	Acenaphthene MW: 154.21	ACENAP
	86-73-7	Fluorene MW: 166.22	FLUORE
	85-01-8	Phenanthrene MW 178.24	PHENAN
	120-12-7	Anthracene MW: 178.24	ANTRAC
	206-44-0	Fluoranthene MW: 202.26	FLANTHE
	129-00-0	Pyrene MW: 202.26	PYRENE
	218-01-9	Chrysene MW: 228.30	CHRYSE
	50-32-8	Benzo(a)pyrene MW: 252.32	BAPYRE

Structure	CAS number	Long	Short
	56-55-3	Benzo(a)anthracene MW: 228.30	BAANTHR
	205-99-2	Benzo(b)fluoranthene MW: 252.32	BBFLANT
	207-08-9	Benzo(k)fluoranthene MW: 252.32	BKFLANT
	193-39-5	Indeno(1,2,3-c,d)pyrene MW: 276.34	I123PYR
	53-70-3	Dibenzo(a,h)anthracene MW: 278.36	DBAHANT
	191-14-2	Benzo(g,h,i)perylene MW: 276.34	B-GHI-PY
Volatile compounds			
CH ₃ -CO-CH ₃	67-64-1	Acetone MW: 58.08	
CH ₂ Cl ₂	75-09-2	Methylene Chloride MW84.93	
	71-43-2	Benzene MW: 78.11	

Structure	CAS number	Long	Short
	108-88-3	Toluene MW: 92.14	
	100-41-4	Ethylbenzene MW: 106.17	
 1,2-dimethylbenzene (ortho-xylene) 1,3-dimethylbenzene (meta-xylene) 1,4-dimethylbenzene (para-xylene)	m,p!xylenes	meta-/para-Xylenes	
	95-47-6	ortho-Xylene MW: 106.17	

CAS: Numbers established by the Chemical Abstract Service of the American Chemical Society

Table 3. PCB congener scientific names and IUPAC numbers.¹

PCB congener	IUPAC number	PCB congener	IUPAC Number
2,4-dichlorobiphenyl	PCB 7	2,2',3,4',5',6-hexachlorobiphenyl	PCB 149
2,4'-dichlorobiphenyl	PCB 8	2,2',3,5,5',6-hexachlorobiphenyl	PCB 151
4,4'-dichlorobiphenyl	PCB 15	2,2',4,4',5,5'-hexachlorobiphenyl	PCB 153
2,2',5-trichlorobiphenyl	PCB 18	2,2',4,4',5,6'-hexachlorobiphenyl	PCB 154
2,4,4'-trichlorobiphenyl	PCB 28	2,2',4,4',6,6'-hexachlorobiphenyl	PCB 155
2,4',5-trichlorobiphenyl	PCB 31	2,3,3',4,4',5-hexachlorobiphenyl	PCB 156
2,2'3,3'-tetrachlorobiphenyl	PCB 40	2,3,3',4,4',5'-hexachlorobiphenyl	PCB 157
2,2'3,5'-trichlorobiphenyl	PCB 44	2,3,3'4,5,5'-hexachlorobiphenyl	PCB 159
2,2',4,5'-tetrachlorobiphenyl	PCB 49	2,3',4,4'5,5'-hexachlorobiphenyl	PCB 167
2,2',4,6-tetrachlorobiphenyl	PCB 50	2,2',3,3',4,4',5-heptachlorobiphenyl	PCB 170
2,2'5,5'-tetrachlorobiphenyl	PCB 52	2,2',3,3',4,4',6-heptachlorobiphenyl	PCB 171
2,2',6,6'-tetrachlorobiphenyl	PCB 54	2,2',3,3',4,5,6-heptachlorobiphenyl	PCB 173
2,3,4,4'-tetrachlorobiphenyl	PCB 60	2,2',3,4,4',5,5'-heptachlorobiphenyl	PCB 180
2,3',4,4'-tetrachlorobiphenyl	PCB 66	2,2',3,4,4',5,6'-heptachlorobiphenyl	PCB 182
2,3',4',5-tetrachlorobiphenyl	PCB 70	2,2',3,4,4',5',6-heptachlorobiphenyl	PCB 183
3,3',4,4'-tetrachlorobiphenyl	PCB 77	2,2',3,4,4',6,6'-heptachlorobiphenyl	PCB 184
2,2',3,3',4-pentachlorobiphenyl	PCB 82	2,2',3,4,5,5',6-heptachlorobiphenyl	PCB 185
2,2',3,4,5-pentachlorobiphenyl	PCB 86	2,2',3,4',5,5',6-heptachlorobiphenyl	PCB 187
2,2'3,4,5'-pentachlorobiphenyl	PCB 87	2,3,3',4,4',5,5'-heptachlorobiphenyl	PCB 189
2,2',3,4',5-pentachlorobiphenyl	PCB 90	2,3,3',4,4',5,6-heptachlorobiphenyl	PCB 190

PCB congener	IUPAC number	PCB congener	IUPAC Number
2,2',3,5',6-pentachlorobiphenyl	PCB 95	2,3,3',4,4',5',6-heptachlorobiphenyl	PCB 191
2,2',3,4',5-pentachlorobiphenyl	PCB 97	2,3,3',4',5,5',6-heptachlorobiphenyl	PCB 193
2,2',4,4',5-pentachlorobiphenyl	PCB 99	2,2',3,3',4,4',5,5'-octachlorobiphenyl	PCB 194
2,2',4,5,5'-pentachlorobiphenyl	PCB 101	2,2',3,3',4,4',5,6-octachlorobiphenyl	PCB 195
2,2',4,5',6-pentachlorobiphenyl	PCB 103	2,2',3,3',4,4',5,6'-octachlorobiphenyl	PCB 196
2,3,3',4,4',5-pentachlorobiphenyl	PCB 105	2,2',3,3',4,5,5',6-octachlorobiphenyl	PCB 198
2,3,3',4',6-pentachlorobiphenyl	PCB 110	2,2',3,3',4,5,5',6'-octachlorobiphenyl	PCB 199
2,3,4,4',5-pentachlorobiphenyl	PCB 114	2,2',3,3',4,5,6,6'-octachlorobiphenyl	PCB 200
2,3',4,4',5-pentachlorobiphenyl	PCB 118	2,2',3,3',4,5',6,6'-octachlorobiphenyl	PCB 201
2,3',4,5',6-pentachlorobiphenyl	PCB 121	2,2',3,3',5,5',6,6'-octachlorobiphenyl	PCB 202
2,3',4,4',5'-pentachlorobiphenyl	PCB 123	2,2',3,4,4',5,5',6-octachlorobiphenyl	PCB 203
3,3',4,4',5-pentachlorobiphenyl	PCB 126	2,3,3',4,4',5,5',6-octachlorobiphenyl	PCB 205
2,2',3,3',4,4',5-hexachlorobiphenyl	PCB 128	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl	PCB 206
2,2',3,3',4,5-hexachlorobiphenyl	PCB 129	2,2',3,3',4,4',5,6,6'-nonachlorobiphenyl	PCB 207
2,2',3,4,4',5'-hexachlorobiphenyl	PCB 138	2,2',3,3',4,5,5',6,6'-nonachlorobiphenyl	PCB 208
2,2',3,4,5,5'-hexachlorobiphenyl	PCB 141		

¹ <http://www.atsdr.cdc.gov/ToxProfiles/tp17-c4.pdf>

Figure 3 shows mean VOC concentrations in the IHC Turning Basin mixed-composite sediment sample. Error bars in Figure 3 are standard errors of the mean. Benzene (34.3 mg/kg), toluene (32.0 mg/kg), and meta-/para-xylenes (35.0 mg/kg) together make up most of the VOC mass in the Turning Basin sediment. VOCs were not measured in the 1987 study (Environmental Laboratory 1987a).

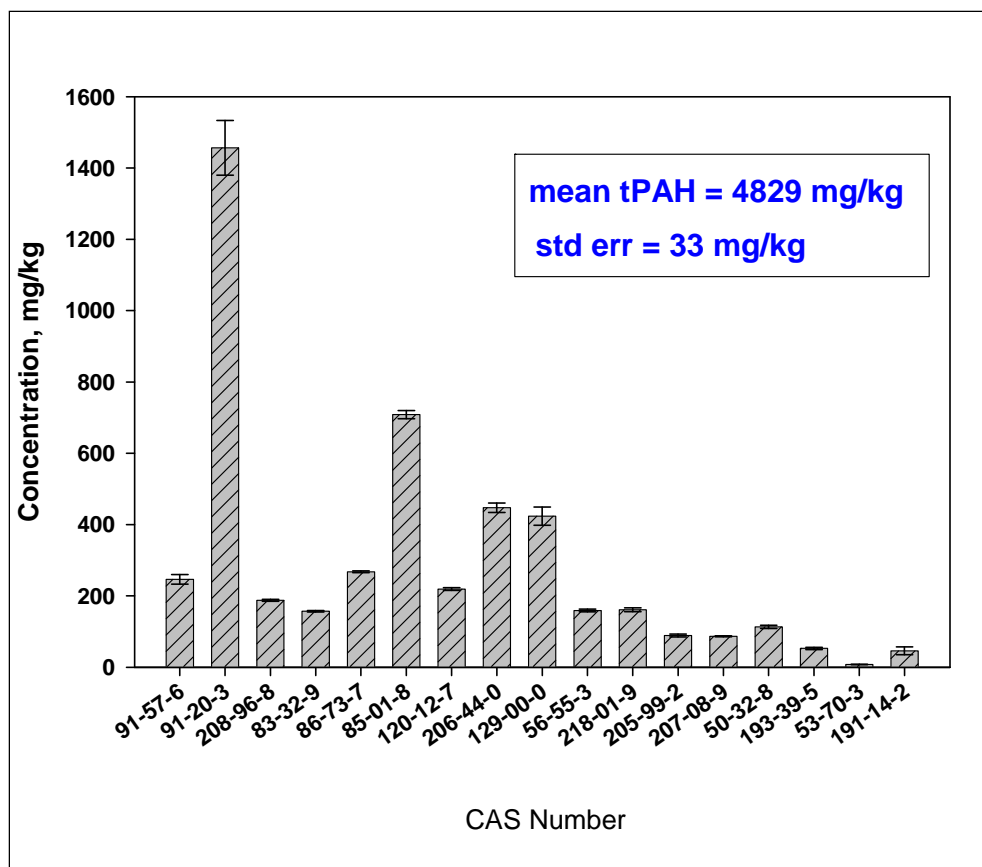


Figure 2. IHC Turning Basin sediment PAH concentrations (composite sample).

Table 4. PAH mass distributions (percent of total PAHs).

PAH	1987	2005
2-Methylnaphthalene	NA	5.10
Naphthalene	61.9	30.2
Acenaphthylene	0.68	3.89
Acenaphthene	2.97	3.25
Fluorene	2.14	5.54
Phenanthrene	6.19	14.7
Anthracene	1.92	4.54
Fluoranthene	4.65	9.26
Pyrene	4.34	8.77
Chrysene	2.85	3.33
Benzo(a)pyrene	2.69	2.34
Benzo(a)Anthracene	2.66	3.29
Benzo(b)fluoranthene	4.34	1.84

PAH	1987	2005
Benzo(k)fluoranthene	NA	1.79
Indeno(1,2,3-c,d)pyrene	1.55	1.09
Dibenzo(a,h)anthracene	NA	0.16
Benzo(g,h,i)perylene	1.08	0.95

NA: not analyzed

1987: Environmental Laboratory (1987a)

2005: this study, composite sample

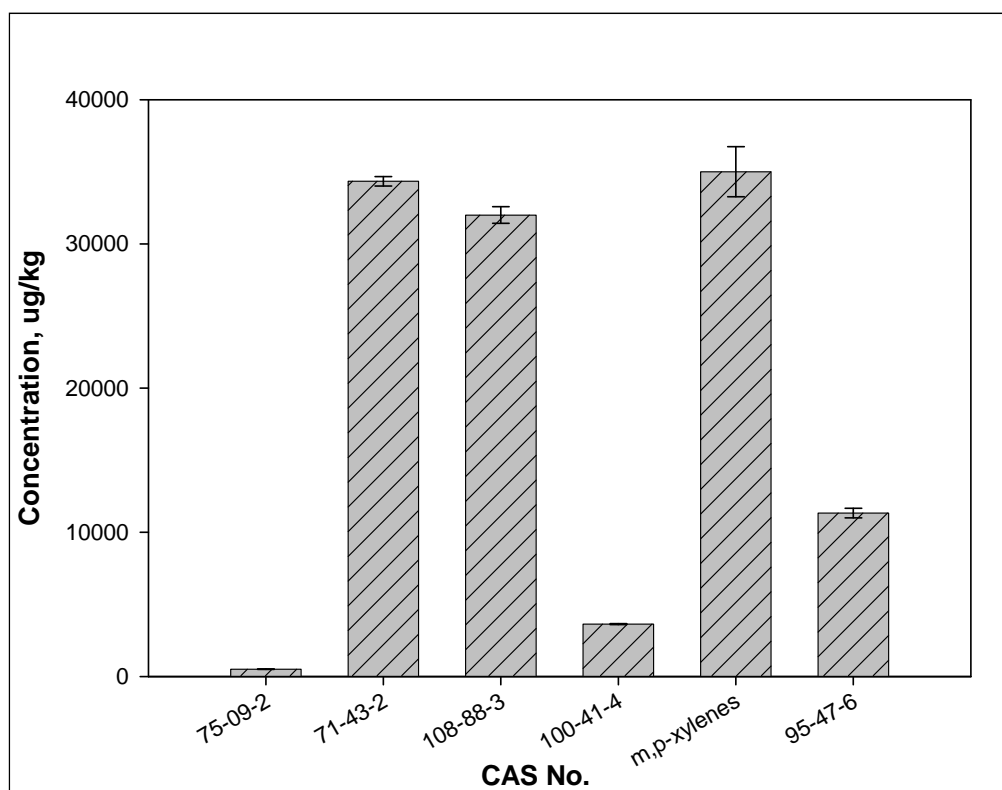


Figure 3. IHC Turning Basin sediment VOC concentrations (composite sample); acetone was below the detection limit (<20,000 $\mu\text{g/kg}$) and is not shown.

2.2.1.3 PCBs

Aroclor-1248 concentration was 19.1 mg/kg (standard error = 0.48 mg/kg) in the Turning Basin sediment. Other Aroclors were non-detect. Aroclor-1248 was 33.4 mg/kg in the 1987 Federal Channel sediment. Table 5 compares PCB congener concentrations in the 1987 Federal Channel sediment and the 2005 Turning Basin sediment.

Table 5. PCB congener concentrations (standard error).

PCB Congener	Concentration, µg/kg		PCB Congener	Concentration, µg/kg	
	1987	2005		1987	2005
PCB 7	<200	43.1 (0.64)	PCB 141	NA	54.3 (2.77)†
PCB 8	10800	2860 (407)	PCB 149	NA	222 (2.65)
PCB 15	NA	2632 (616)	PCB 151	NA	73.8 (0.85)
PCB 18	NA	3754 (75.4)	PCB 153	2200	‡
PCB 28	19500	3590 (49.5)	PCB 154	NA	<64
PCB 31	NA	3182 (57.7)	PCB 155	NA	<64
PCB 40	NA	603 (5.78)	PCB 156	NA	35.5 (1.35)†
PCB 44	NA	1471 (5.5)	PCB 157	NA	<64
PCB 49	3500	1432 (30.6)	PCB 159	NA	<64
PCB 50	19300	<64	PCB 170	NA	67.1 (1.34)
PCB 52	19500	1496 (15.6)	PCB 171	NA	22.1 (1.03)†
PCB 54	NA	<64	PCB 173	NA	<64
PCB 60	NA	486 (6.17)	PCB 180	1980	183 (13.0)
PCB 66	NA	‡	PCB 182	NA	<64
PCB 70	31900	1490 (15.5)	PCB 183	NA	41.6 (0.68)†
PCB 77	NA	242 (7.22)	PCB 184	NA	<64
PCB 81	NA	<64	PCB 185	NA	<64
PCB 82	NA	<64	PCB 187	NA	95.4 (1.65)
PCB 86/97	5200	179 (20.1)	PCB 189	NA	<64
PCB 87	5700	261 (3.33)	PCB 190	NA	<64
PCB 90	NA	37.6 (1.92)†	PCB 191	NA	<64
PCB 95	NA	567 (30.3)	PCB 193	NA	172 (2.11)
PCB 99	NA	222 (0.23)	PCB 194	NA	49.2 (0.50)
PCB 101	1700	496 (1.70)	PCB 195	NA	<64
PCB 103	NA	185 (15.7)	PCB 196	NA	29.5 (0.94)
PCB 105	NA	176 (2.73)	PCB 198	NA	<64
PCB 110	NA	514 (19.6)	PCB 199	NA	<64
PCB 114	NA	<64	PCB 200	NA	<64
PCB 118	NA	328 (3.83)	PCB 201	NA	47.8 (1.41)†
PCB 121	NA	<64	PCB 202	NA	<64
PCB 123	NA	<64	PCB 203	NA	32.9 (0.96)†
PCB 126	NA	<64	PCB 205	NA	<64
PCB 128	NA	40.3 (1.08)	PCB 206	NA	<64
PCB 129	NA	<64	PCB 207	NA	<64
PCB 138	3700	239 (6.68)	PCB 208	NA	<64

†: concentration of analyte is above the minimum detection limit but below the lower reporting limit.

‡: analyte could be resolved due to co-elution with other analytes on both columns

NA: not analyzed

1987: Environmental Laboratory (1987b)

2005: this study

Although the Aroclor-1248 concentrations were somewhat similar for the 1987 and 2005 IHC sediments, congener concentrations were quite different. This difference could be attributed to different analytical techniques. Much progress has been made in the last 20 years on PCB congener analysis. The 1987 study was the first time that the ERDC analytical laboratory measured PCB congeners in sediment samples. At that time, there were very few PCB congener standards available. That is why so few PCB congeners were measured in the 1987 study. Today, PCB congener analysis is routine; in 1987, PCB congener analysis was a research project in its own right.

2.2.1.4 TOC and oil and grease

TOC and oil and grease concentrations in Indiana Harbor sediments, Federal channel sediment from 1987, and Turning Basin sediment 2005, are shown in Table 6.

Table 6. TOC and oil and grease levels (standard error).

Parameter	1987	2005
TOC (percent sediment dry weight)	7.39	8.51 (0.0208)
Oil and grease (percent sediment dry weight)	3.88	4.16 (0.105)

1987: Environmental Laboratory (1987a)

2005: this study

2.2.1.5 Sediment chemical characterization summary

Collection of sediment with an adequate load of volatiles and semi-volatiles for measurement of volatile emissions under a variety of test conditions was a critical concern for this study. It would not be sufficient to report non-detects or volatile fluxes so low that analytical and experimental error made it impossible to determine activated carbon efficacy in controlling air emissions. The CELRC used historical data to select a sampling location in the Indiana Harbor Turning Basin expected to be sufficiently contaminated.

On the basis of data from prior studies of Indiana Harbor sediment, the sediment collected for this study is sufficiently contaminated with semi-volatiles (PAHs) and most likely volatiles in order to meet the study objectives. In the 1987 study (Environmental Laboratory 1987b), PAH and PCB concentrations in sediment before and after 6 months of damp exposure to air with weekly mixing showed decreases of 86 and 83%,

respectively. Volatilization was probably the primary process responsible for the dramatic decreases in PAH and PCB concentrations that resulted from aging damp sediment. PAH concentrations in the sediment collected in this study were similar to those in the sediment collected in 1987. Thus, volatilization of PAHs in exposed sediment tests is expected. Fluxes were not measured in the 1987 study, but PAH flux from exposed Indiana Harbor sediment has been measured in other studies (Ravikrishna et al. 1998, 2001) using sediment that was much less contaminated than that collected for this study. Valsaraj et al. (1997) measured phenanthrene and pyrene fluxes from exposed Rouge River sediment that was much less contaminated than the sediment collected for this study. Volatile flux measurements on suspended sediment are very limited. However, Price et al. (2001) measured PAH fluxes from suspended IHC sediment that was much less contaminated than the sediment collected in this study.

2.2.2 Physical characteristics

Physical properties were determined using U.S. Army Corps of Engineers (USACE) methods that are equivalent to USEPA methods. Water content, specific gravity, Atterberg limits, and grain size analysis were determined as provided in the USACE Soils Testing Manual (USACE 1980; update of 1970). Results are listed in Table 6. Grain size distribution is shown in Figure 4.

Table 7. IHC Turning Basin sediment physical properties.

Property	Result
Classification	Organic clay (OH), gray
Specific gravity	2.88
Percent gravel	0.0
Percent sand	3.5
Percent fines	96.5
Atterberg limits	
Liquid limit	82
Plastic limit	38
Plasticity index	44
Water content	112.4 %

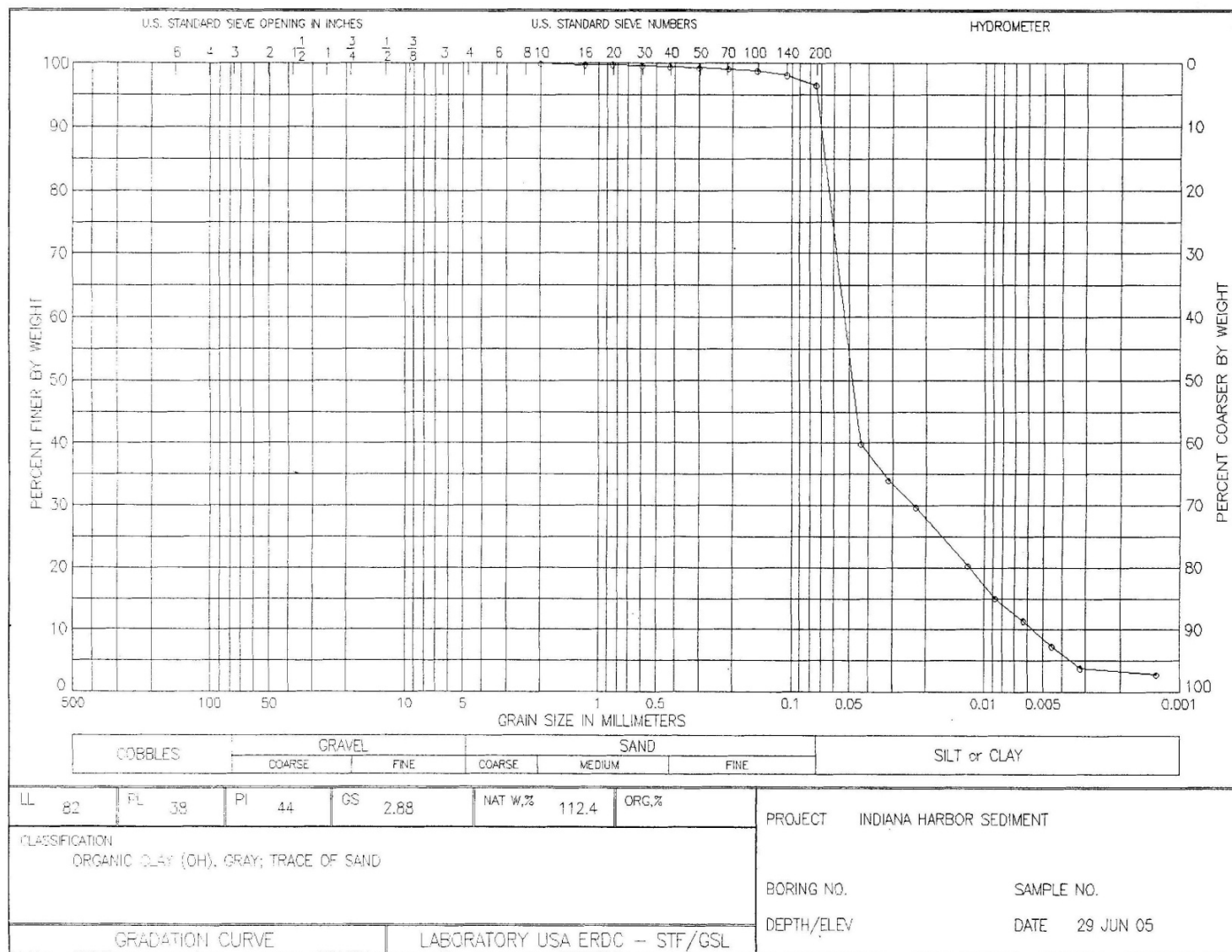


Figure 4. IHC Turning Basin sediment grain size distribution

3 Carbon Selection

This chapter describes how commercially available activated carbons were screened and specific carbons were selected for further study. Selection was based on three factors as follows: sorptive properties, settling properties, and cost. As is the nature of a screening process, coarse information on sorption, settling, and cost was developed and used to select a PAC and a granular activated carbon (GAC) for further study.

Several tests have been developed by activated carbon manufacturers to characterize the sorptive properties of carbon. These include phenol number, iodine number, and molasses number. Iodine number is a measure of porosity and is related to the ability to adsorb organic compounds. Settling behavior was an important physical characteristic in the selection process. Information from manufacturer product bulletins was collected and compiled for evaluation. Eleven carbon suppliers were contacted, and samples of activated carbon were requested (pro bono) for use in a simple settling test described later. Carbon suppliers that responded to the request for pro bono carbon samples are listed in Table 8.

Table 8. PAC responsive carbon suppliers.

Company	Address	PAC supplied (type)	Source	Iodine number ¹ (mg/g)
General Carbon Corp.	33 Paterson St Paterson, NJ 07501	GC Powered	Virgin carbon derived from bituminous coal	800 (min)
TIGG Corp.	800 Old Pond Rd Suite 706 Bridgeville, PA 15017	TIGG 5D	Virgin carbon derived from bituminous coal	1000 (min)
Calgon Carbon Corp.	P.O. Box 717 Pittsburgh, PA 15230	WPX-D WXP-Z	Reactivated carbon derived from bituminous coal	800 (min)
Winfield Industries, Inc.	P.O. Box 626 Monument, CO 80132	WF-PAC-600	Virgin carbon derived from bituminous and sub-bituminous coal	

¹ Iodine numbers provided by suppliers

The iodine numbers in Table 8 are all very similar, and most PAC has an iodine number of 800 to 1000. At this point in the evaluation, the PAC samples in Table 8 were considered equivalent in terms of reactivity. Costs are not listed in Table 8 because suppliers do not routinely provide a cost until a request for quotes is received. Cost depends on distance from the manufacturing facility and quantity ordered. Reactivated carbon usually runs about one-half the cost of virgin carbon and has about the same reactivity as virgin carbon. Reactivated carbon would likely be favored over virgin carbon at full scale because of cost. Several companies supply reactivated carbons, but only one supplier suggested the use of reactivated carbon.

Settling behavior is important because one of the potential applications of activated carbon for the IHC project is to apply PAC to settling ponds, either aerially or by pipeline injection. A simple column settling test was therefore set up to compare carbon settling properties. In the carbon column settling test, PAC was weighed and placed in a 125-ml plastic bottle. Next, 100 ml of reverse-osmosis water was measured in a 100-ml graduated cylinder and poured into the 125-ml plastic bottle with PAC. The PAC and water were mixed by vigorous hand shaking for 30 seconds followed by mixing on a horizontal, reciprocating shaker at 200 rpm for 30 minutes. After shaking, the PAC/water mixtures were poured into 100-ml graduated cylinders and allowed to settle at room temperature ($\sim 20^{\circ}\text{C}$). Settling of the interface between clarified and turbid water was measured with time. Two sets of tests were run, as indicated in Table 9, one set with 1 g/L PAC and one with 5 g/L PAC. The reactivated carbon, WPX-D, settled about as well or better than the virgin carbons. Photos of the carbon settling tests are shown in Figures 5 through 8. WPX-D was selected as the PAC for further study. A reactivated GAC (WF-GAC) also supplied by Calgon Corporation was chosen as the GAC for further study.

Table 9. Carbon settling test results.

Elapsed time (min)	PAC	Interface ¹	Remarks
Test I (5g/L PAC)			
3	A	54	
	B	100	
	C	46	
	D	90	
39	A	20	grey supernate
	B	100	clearing but no interface
	C	22	
	D	35	very clear supernate
1095	A	17	clear supernate
	B	14	mild turbidity in supernate
	C	16	very clear supernate
	D	26	clear supernate
Test II (1 g/L PAC)			
5	B	100	
	C	100	
	D	13	rapid settling, turbid supernate
	E	100	
20	B	100	
	C	100	
	D	8	supernate turbid, but clearing
	E	100	
60	B	97	
	C	5	
	D	8	
	E	98	
120	B	80	heavy turbidity in supernate
	C	5	mild turbidity in supernate
	D	8	mild turbidity in supernate
	E	74	heavy turbidity in supernate
180	B	55	turbid supernate
	C	5	light turbidity in supernate

Elapsed time (min)	PAC	Interface ¹	Remarks
	D	8	light turbidity in supernate
	E	63	turbid supernate
900	B	3	light turbidity in supernate
	C	4	light turbidity in supernate
	D	7	very clear supernate
	E	4	light turbidity in supernate

¹ Cylinder graduations

A: TIGG 5D

B: GC Powdered

C: WPX-D

D: WF-PAC-600

E: WPX-Z



Figure 5. Carbon settling Test I – 3 minutes (A: TIGG 5D; B: GC Powdered; C: WPX-D; D: WF-PAC-600).

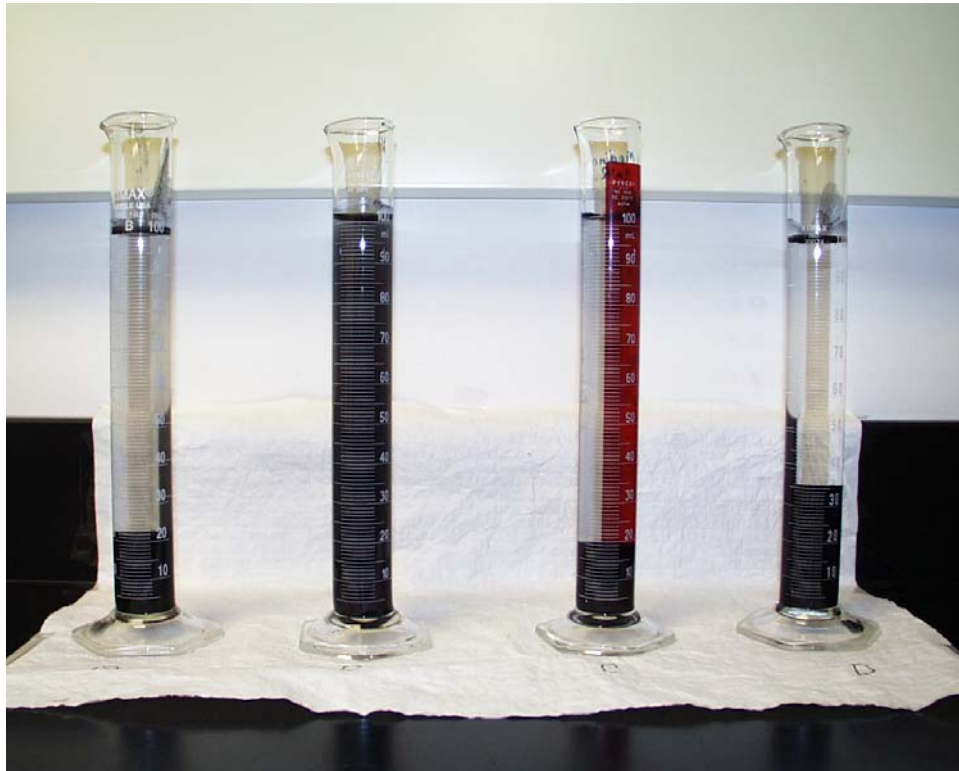


Figure 6. Carbon settling Test I – 39 minutes (A: TIGG 5D; B: GC Powdered; C: WPX-D; D: WF-PAC-600).

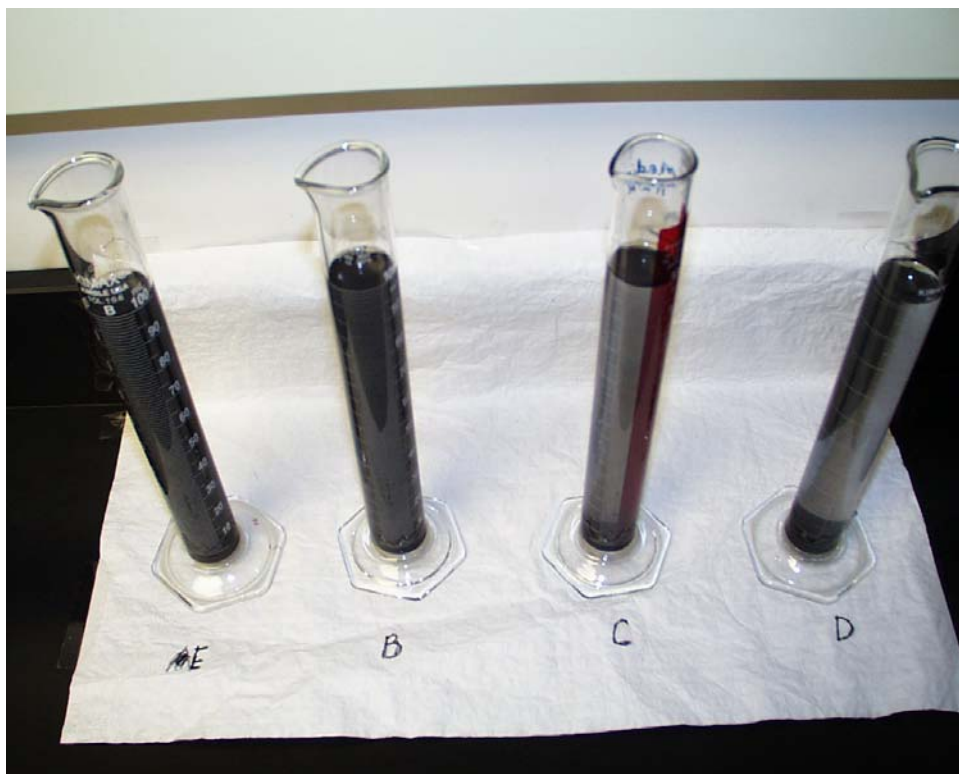


Figure 7. Carbon settling Test II – 60 minutes (A: TIGG 5D; B: GC Powdered; C: WPX-D; D: WF-PAC-600).



Figure 8. Carbon settling Test II- 900 minutes (A: TIGG 5D; B: GC Powdered; C: WPX-D; D: WF-PAC-600).

4 Carbon Adsorption Isotherms

4.1 Introduction

Carbon adsorption isotherms were developed to estimate PAC dosages for the flux experiments involving suspended solids, to provide partitioning coefficients for use in predictive volatile emission models, and to provide information on the effectiveness of a GAC bed for removal of dissolved VOC and PAH in settling basin effluent. Adsorption isotherms characterize the equilibrium between the amount of contaminant that adsorbs to activated carbon and the concentration of the dissolved contaminant. Dissolved concentrations are important because organic chemicals must first dissolve in order to volatilize from suspended sediment (Thibodeaux 1996).

Reduction of dissolved organic compound concentrations by adsorption to activated carbon therefore reduces volatile emissions. Activated carbon has been widely used for many years to remove organic chemicals from water and air streams. The mechanisms of adsorption and principles of design are well known (Eckenfelder 1966; Weber 1972; Metcalf and Eddy, Inc. 1979; Droste 1997; Reible 1999). The Freundlich isotherm is commonly used to model sorption equilibria. At low dissolved organic compound concentrations, the Freundlich isotherm is linear, i.e., linear isotherms apply when dissolved concentrations are sufficiently low, which depends on the solubility of the chemical.

Activated carbon suppliers often provide adsorption isotherms as part of their product literature. Such isotherms cannot be used to represent the equilibrium between dissolved and adsorbed values for IHC settling basin effluent because of competition for adsorption sites among dissolved organic matter, oil and grease, and the mixture of contaminants. Background organic matter strongly competes with target organic compounds for adsorption sites on activated carbon. As a result, the adsorption capacity for a target compound is often far below that indicated by the single-solute isotherm in distilled water. In the case of mixtures, competitive adsorption occurs since the available surface area of the activated carbon will be occupied, to varying degrees, by all the dissolved components. As a result, the solid-phase concentration of a single contaminant will generally be reduced as compared with the loading that can be reached in the absence of other competing components. For these reasons, it was necessary to prepare

a simulated IHC settling basin effluent for developing representative adsorption isotherms.

The Freundlich equation is $q = K_f C_e^{1/n}$ where q is the amount of chemical sorbed per unit weight activated carbon, C_e is the equilibrium chemical concentration, and K_f and n are empirical coefficients. K_f and n are determined by fitting the Freundlich equation to batch adsorption isotherm data. For sufficiently low dissolved chemical concentrations, $n = 1$, and K_f can be replaced with K_d , a linear partitioning coefficient. The range of dissolved chemical concentrations for which K_f can be replaced with K_d is indicated by the adsorption isotherm. Replacement of the Freundlich sorption model with a linear partitioning model simplifies the mathematics needed to model volatile emissions from water when activated carbon is present in suspension.

An alternate equation for modeling activated carbon contaminant adsorption is the Langmuir isotherm equation. The basis for this equation is the concept that the adsorption rate is proportional to the difference between the amount of adsorbate at a particular concentration and the amount that can be adsorbed at that concentration (Metcalf and Eddy 1979). It is generally written $q = (abC)/(1+bC)$, where q is the amount of contaminant adsorbed per unit weight activated carbon, C is the contaminant concentration, and a and b are empirical constants. Rearranging the equation to a linear form $C/q = (1/ab) + (1/a)C$ allows determination of the constants by plotting C/q vs. C .

4.2 Methods

4.2.1 Elutriate preparation and characterization

Simulated IHC elutriate was prepared using the composite sediment sample described in Section 2.2 and distilled-deionized water at a 10:1 liquid:solids ratio. Sediment and distilled-deionized water were mixed in 4-L amber glass jars on a reciprocating shaker at 180 rpm. Care was taken to ensure zero head-space in the glass jar. After shaking for 24 hr, solids-liquid separation was accomplished by centrifugation in 500-ml stainless steel tubes at 6000 rpm 30 min followed by filtration through Whatman glass (binderless) pre-filters and then through 0.7-micron mean pore size glass (binderless) filters. The various batches of the prepared elutriate were blended together into one 37-L batch for characterization and use in the adsorption isotherm testing.

A sample of the batch of composite sediment that was used to prepare the elutriate for isotherm testing was analyzed for VOCs, PAHs, TOC, and oil and grease using the methods listed in Table 1. The elutriate was analyzed for VOC, PAHs, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) using the methods listed in Table 10. Sediment and elutriate analyses for VOCs and PAHs were not replicated. The sediment was analyzed in triplicate for oil and grease and TOC, and the elutriate was analyzed in triplicate for BOD and COD. Results are listed in Table 11. The batch of composite sediment taken for isotherm testing was similar in PAH contamination to the overall composite sediment. However, VOCs were substantially reduced in the batch of sediment taken for isotherm testing in comparison to the overall composite sediment. The differences were so large as to not likely be due to variability in chemical analyses. VOCs might have been lost during sediment handling, mixing, and sampling, or the differences might be due to sediment chemical heterogeneity. The latter explanation is not consistent with the similarities in PAH concentrations between the two sediments. It appears, therefore, that the VOCs were lost by volatilization during handling, mixing, and sampling.

4.2.2 Adsorption isotherm procedure

Adsorption isotherms were generated using the batch equilibrium technique in triplicate for one PAC (WPX-D, Calgon Corporation) and one reactivated GAC (WF-GAC, Calgon Corporation) using the simulated settling basin effluent described in Section 4.2.1. Fixed amounts of PAC or GAC were added to simulated effluent at activated carbon concentrations of 0.01, 0.05, 0.1, 0.5, and 1.0 g/L in 500-mL centrifuge tubes for PAHs and VOCs. The tubes and flasks were shaken at $25 \pm 0.5^{\circ}\text{C}$ for 24 hr (default mixing time for carbon isotherm experiments) on a horizontal reciprocating shaker at 180 rpm. After adsorption, the dissolved phase was isolated by centrifugation at 6000 rpm for 30 minutes in stainless steel centrifuge tubes followed by filtration through Whatman binderless glass fiber prefilters and then through Whatman 0.7- μm binderless glass fiber filters. The dissolved phase was analyzed for equilibrium chemical concentrations using the methods in Table 10. Contaminant mass on the carbon phase was calculated by difference between the contaminant concentration in the simulated effluent and the equilibrium dissolved concentration. A table of adsorbed contaminant concentrations, q , and dissolved contaminant equilibrium concentrations, C , was developed and plotted (different activated carbon concentrations yielding different q and C concentrations). Raw data for dissolved contaminant concentrations from the batch adsorption tests are presented in Appendix B.

Table 10. Chemical analytical methods for water.

Analyte	Lower Reporting Limit ²	Extraction Method ¹	Quantitation Method ¹
VOCs	2.0 µg/L	5030B	8260B
PAHs	0.10 µg/L	3510C	8270C
Oil and grease	33 mg/kg	9071B	9071B
TOC	0.25 mg/L	Not applicable	9060
BOD	1.0 mg/L	Not applicable	4305.1
COD	20 mg/L	Not applicable	410.4

1 Method numbers refer to SW-846 (USEPA 1996).

2 LRL is based on 100% solids. Dredged material containing moisture will raise the LRL.

3 Except for acetone which is 25 µg/L.

Table 11. Chemical analyses of sediment and elutriate for isotherm testing.

Analyte	Sediment Concentration ¹		Elutriate Concentration, µg/L
	Isotherm	Composite (std err)	
Acetone	<21000 µg/kg	<20500 µg/kg	63
Methylene chloride	1200 µg/kg	500 (15.3) µg/kg	N.D.
Benzene	2000 µg/kg	34333 (333) µg/kg	16.3
Toluene	3560 µg/kg	32000 (577) µg/kg	7.1
Ethylbenzene	1500 µg/kg	3633 (33.3) µg/kg	0.7
Meta-/para-Xylenes	17700 µg/kg	35000 (1732) µg/kg	Not Analyzed
Ortho-Xylene	5710 µg/kg	11333 (333) µg/kg	Not Analyzed
Total Xylenes ²	23410 µg/kg	46333 µg/kg	13.8
2MeNAPH	194 mg/kg	246 (13.4) mg/kg	10.8
NAPHTH	975 mg/kg	1457 (76.9) mg/kg	562
ACENAY	103 mg/kg	188 (2.60) mg/kg	26.9
ACENAP	240 mg/kg	157 (2.08) mg/kg	23.8
FLUORE	271 mg/kg	268 (2.40) mg/kg	26.7
PHENAN	810 mg/kg	708 (11.5) mg/kg	39.9
ANTRAC	275 mg/kg	219 (3.67) mg/kg	15
FLANTHE	595 mg/kg	447 (13.2) mg/kg	12.8
PYRENE	357 mg/kg	424 (25.6) mg/kg	7.7
CHRYSE	219 mg/kg	161 (5.51) mg/kg	0.86
BAPYRE	211 mg/kg	113 (4.58) mg/kg	0.39
BAANTHR	248 mg/kg	159 (3.79) mg/kg	1.26
BBFLANT	176 mg/kg	89 (4.13) mg/kg	0.56
BKFLANT	158 mg/kg	86.6 (1.45) mg/kg	0.18

Analyte	Sediment Concentration ¹		Elutriate Concentration, µg/L
	Isotherm	Composite (std err)	
I123PYR	118 mg/kg	52.6 (3.05) mg/kg	0.13
DBAHANT	19.7 mg/kg	7.49 (0.314) mg/kg	.03J
B-GHI-PY	97.7 mg/kg	45.8 (10.9) mg/kg	0.11
Oil and Grease, %	Not Analyzed	4.16 (1.05) mg/kg	Not Analyzed
TOC, %	Not Analyzed	8.51 (0.021) mg/kg	Not Analyzed
BOD, mg/L			11.8 (0.1)
COD, mg/L			121 (14.1)

¹ Isotherm sediment is the batch of sediment used for the isotherm test and composite sediment is the sediment described in Section 2.2.

² Sum of ortho, meta, and para xylenes.

4.3 Reduction of VOC and PAH dissolved concentrations

Adsorption isotherms are discussed in Sections 4.4, 4.5, and 4.6. This section presents reductions in VOC and PAH concentrations as a function of activated carbon concentration. Discussion of PAHs is broken into two subsections, low molecular weight (LMW) PAHs and high molecular weight (HMW) PAHs. Low molecular weight PAHs are those PAHs with three or less rings. High molecular weight PAHs are all others.

4.3.1 LMW PAHs

Figure 9 shows percent reduction of LMW PAH concentrations in the IHC simulated effluent for each PAC dosage. The PAH in highest concentration in the simulated IHC effluent was naphthalene; naphthalene was also the most difficult LMW PAH to remove by adsorption to activated carbon as indicated in Figure 9. A PAC dose of 0.5 g/L was sufficient to remove all the LMW PAHs under the completely mixed conditions of the test.

The negative removals shown in Figure 9 resulted from higher chemical concentrations after contact with PAC than the starting chemical concentration in the simulated IHC effluent and may be due to chemical analytical variability. Each PAC dosage was prepared in triplicate, producing three solutions for analysis of dissolved PAH concentrations; however, the starting concentration in the simulated effluent was not analyzed in triplicate, and it could be somewhat in error or may have losses by volatilization of the smaller volatile compounds during sampling and handling. Negative removals were observed at the lowest PAC dosage, and at this dosage, the concentration at equilibrium with PAC and the starting concentration in the

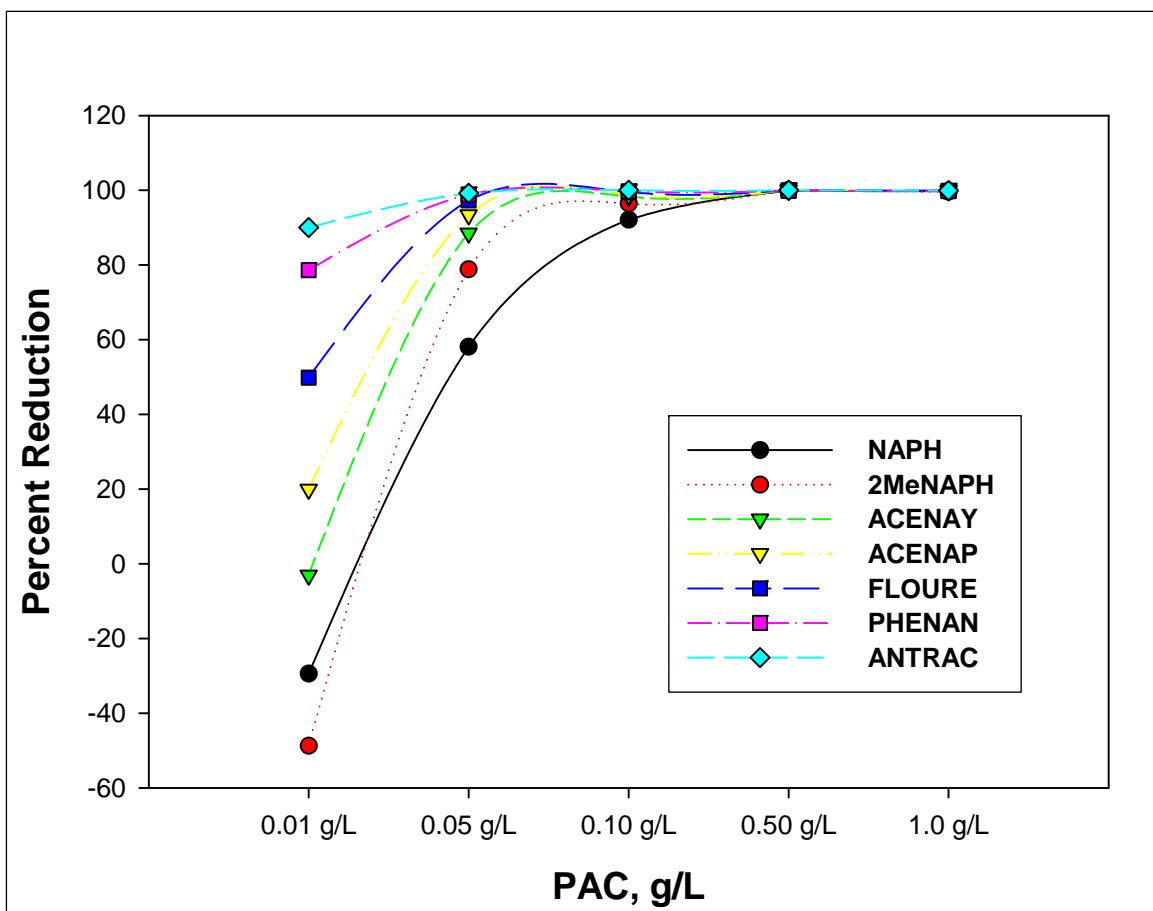


Figure 9. Percent reduction in LMW PAH concentration vs. PAC dosage (note x-axis not to scale).

simulated effluent would be expected to be close together. The percent reductions in Figure 9 are mean values based on the triplicate analyses of the dissolved phase. Interestingly, the trend from negative removal to positive removal for the 0.01-g/L PAC dosage shows a correlation with molecular weight. Percent removal for all PAC dosages also shows a correlation with molecular weight in Figure 9. The more rings and higher molecular weight, the more removed by PAC.

Figure 10 shows percent reduction of LMW PAH concentrations in the IHC simulated effluent for each GAC dosage. 2-Methylnaphthalene was slightly more difficult for GAC to remove than naphthalene. GAC removals of naphthalene, acenaphthylene, and acenaphthene were similar. GAC removals of fluorene, phenanthrene, and anthracene correlated with molecular weight. There was only one negative removal for GAC compared to three for PAC. A GAC dose of 1 g/L was sufficient to remove all the LMW PAHs under the completely mixed conditions of the test.

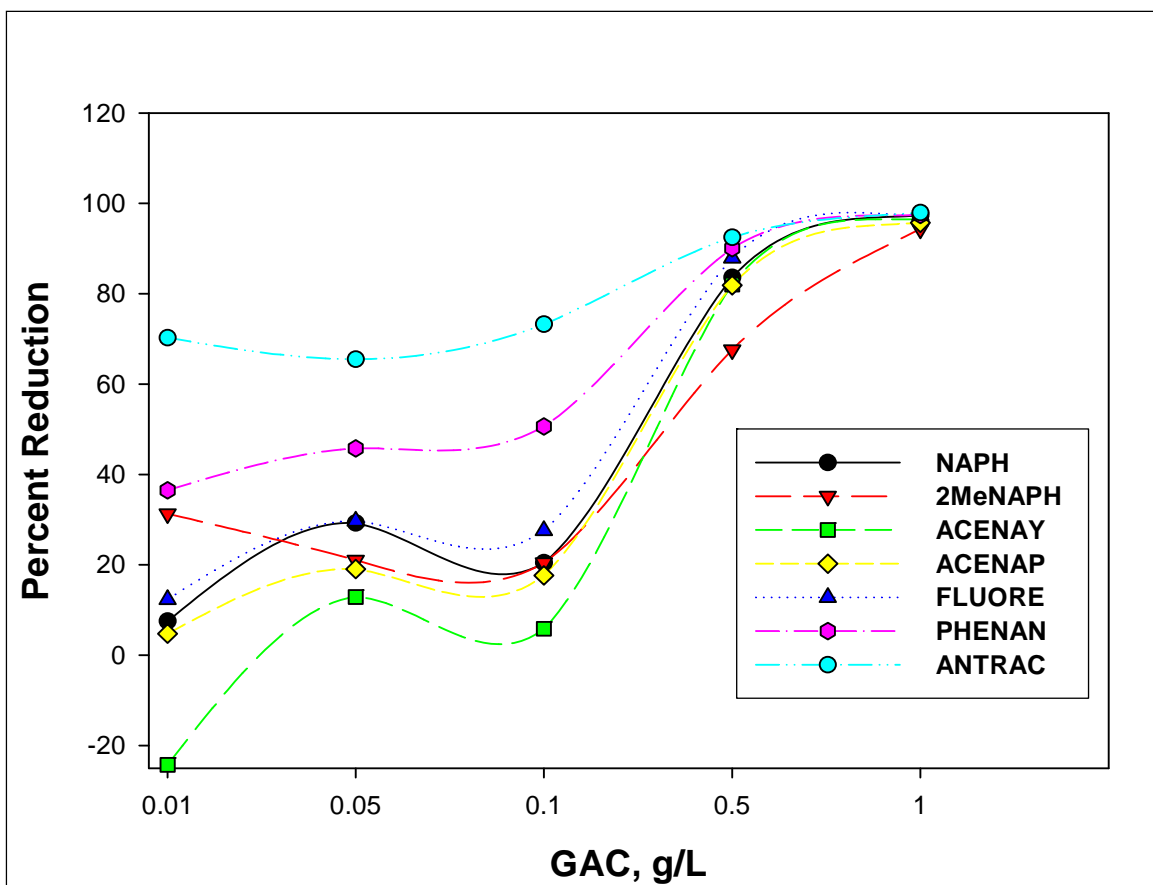


Figure 10. Percent reduction in LMW PAH concentration vs. GAC dosage (note x-axis not to scale).

4.3.2 HMW PAHs

Figure 11 shows percent reduction of HMW PAH concentrations in the IHC simulated effluent for each PAC dosage. Not shown are dibenzo(a,h)anthracene and benzo(g,h,i)perylene; the concentrations of these two PAHs in the simulated IHC effluent were too low for reliable calculation of percent reduction. PAC was very effective for the reduction of dissolved HMW PAHs. A PAC dose of 0.1 g/L was sufficient to reduce all the HMW PAHs under the completely mixed conditions of the test.

Figure 12 shows percent reduction of HMW PAH concentrations in the IHC simulated effluent for each GAC dosage. Not shown are dibenzo(a,h)-anthracene and benzo(g,h,i)perylene; their concentrations were too low in the simulated IHC effluent for reliable calculation of percent reduction. Although effective for the reduction of dissolved HMW PAHs, GAC was not as effective as PAC because PAC has a greater surface area compared to GAC; therefore, more adsorption sites are exposed. A GAC dose of more than 1 g/L would be required to reduce all the HMW PAHs.

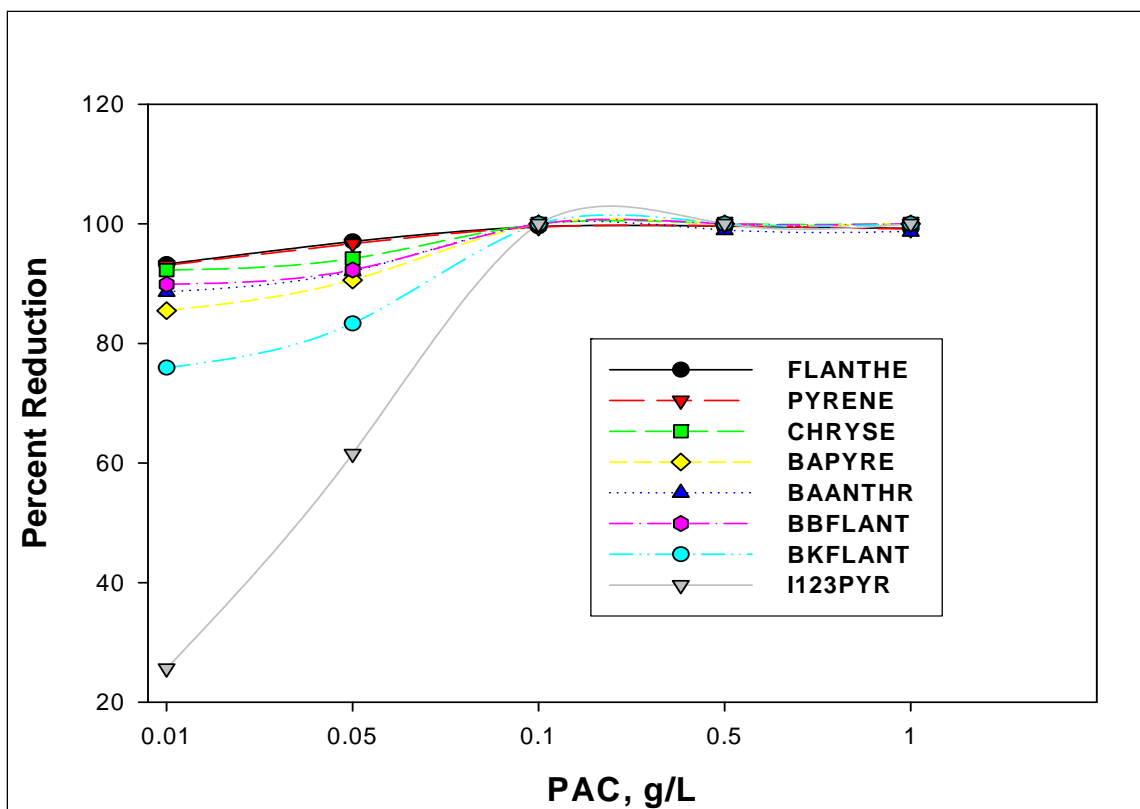


Figure 11. Percent reduction in HMW PAH concentration vs. PAC dosage (note x-axis not to scale).

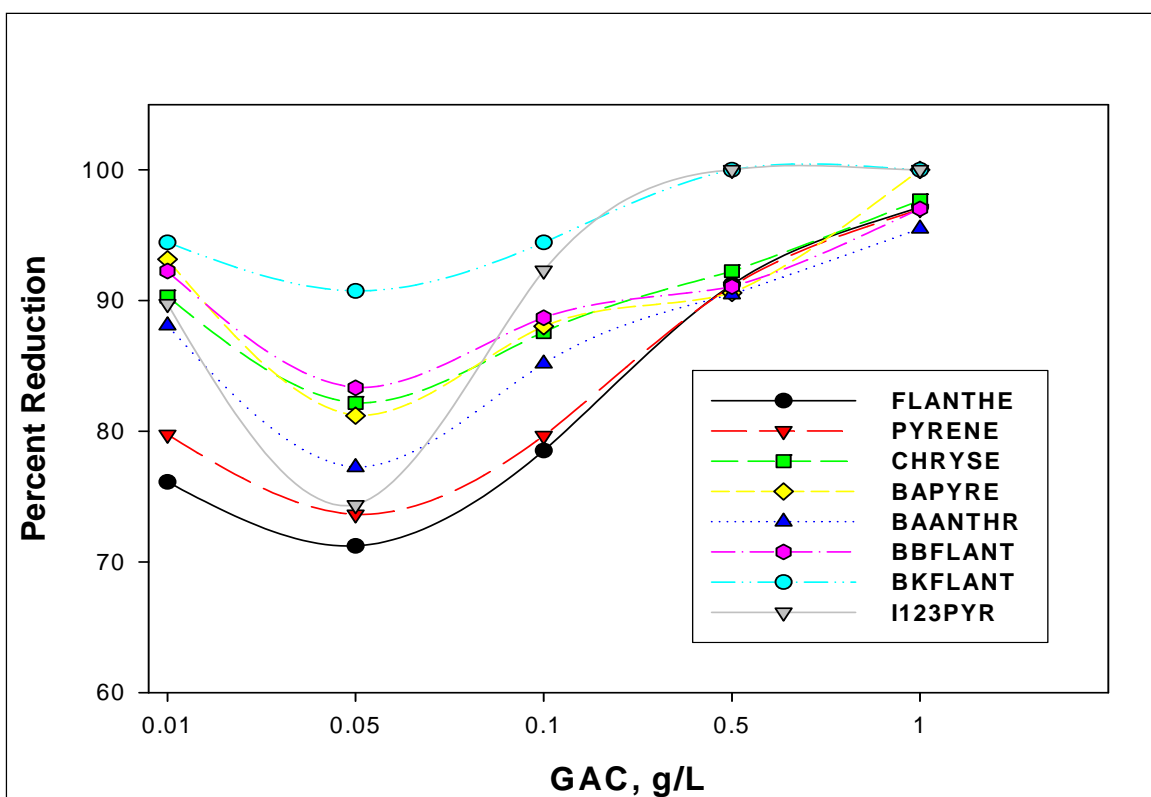


Figure 12. Percent reduction in HMW PAH concentration vs. GAC dosage (note x-axis not to scale).

4.3.3 VOCs

Figures 13 and 14 show percent reduction of VOC concentrations in the IHC simulated effluent for each dosage of PAC and GAC, respectively. Not shown are methylene chloride and ethylbenzene; methylene chloride was not detected in the IHC simulated effluent nor during the adsorption test, and the concentration of ethylbenzene was too low in the simulated IHC effluent and in the effluent after contact with activated carbon for reliable calculation of percent reductions. Although acetone was below the detection limit in the IHC Turning Basin sediment (both composite and the sample used for the adsorption tests), acetone was measurable in the simulated effluent. Acetone removals were therefore included in Figures 13 and 14. Negative removals resulted from the low PAC and GAC dosages. As previously discussed, this may be due to uncertainty about the starting concentrations in the simulated effluent used in the adsorption test due to potential losses by volatilization of the smaller volatile compounds during sampling and handling. As expected, the PAC was more effective at removing VOCs than the GAC. Neither form of activated carbon was completely effective in removing VOCs at the highest dosage tested. Substantially more than 1 g/L would be required for both forms of activated carbon to completely remove all VOCs. Acetone was the most difficult VOC to remove.

4.4 PAH adsorption isotherms

PAH Freundlich and linear adsorption isotherms for PAC are shown in Figure 15. The points shown are for individual replicates, not means of the replicates. The adsorption experiments produced 15 potential pairs of q and C values for plotting – 5 PAC dosages in triplicate (Section 4.2.2). None of the plots in Figure 15 have all 15 potential q - C pairs. Two problems with calculating the q value for a measured C value were encountered. In some instances the dissolved concentration after contact with PAC was higher than the contaminant concentration in the simulated effluent prior to contact with PAC (described in Section 4.3 as negative removals). This was especially true at low PAC dosage. The calculated adsorbed concentration in this case is negative – unreasonable. This type of problem occurred for naphthalene, 2-methylnaphthalene, and acenaphthylene, resulting in negative removals at low PAC dosages (Figure 9). The dissolved concentrations of dibenzo(a,h)anthracene after equilibrium with PAC were slightly higher than the concentration in the simulated effluent, but all (before and after contact with PAC) were so near the lower reporting limit that this PAH for all practical purposes did not

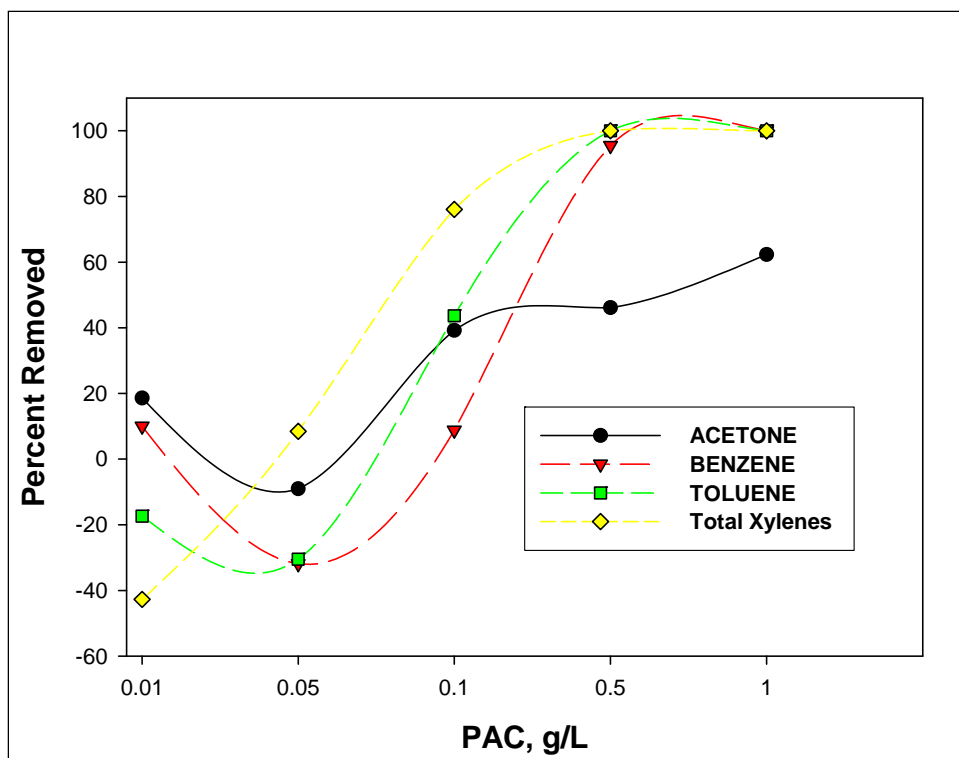


Figure 13. Percent reduction in VOC concentration vs. PAC dosage (note x-axis not to scale).

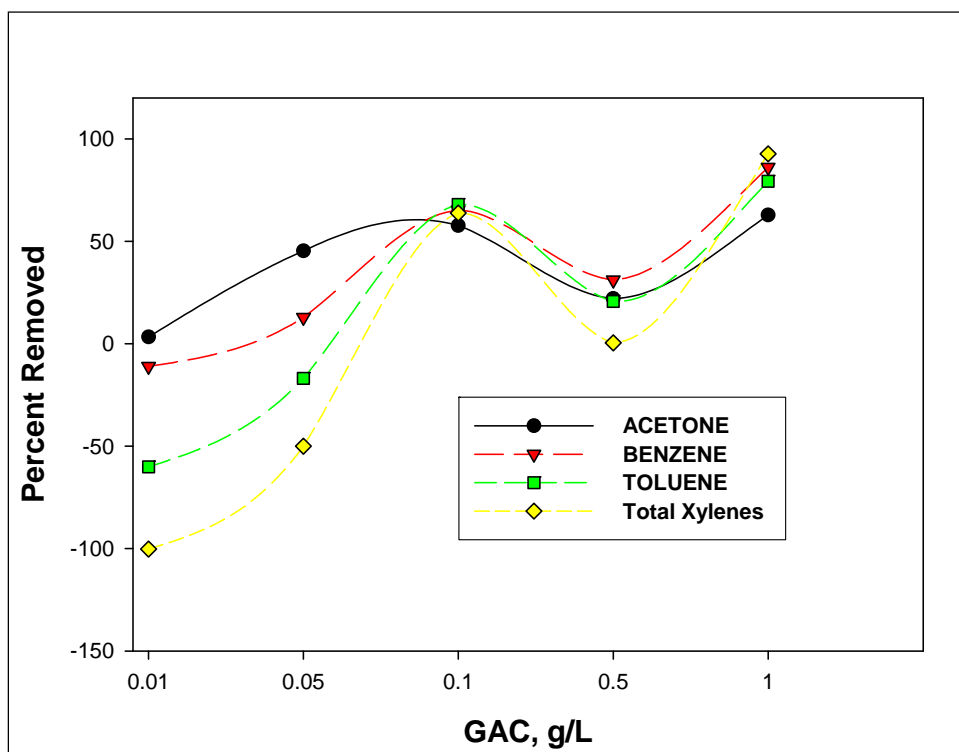


Figure 14. Percent reduction in VOC concentration vs. GAC dosage (note x-axis not to scale).

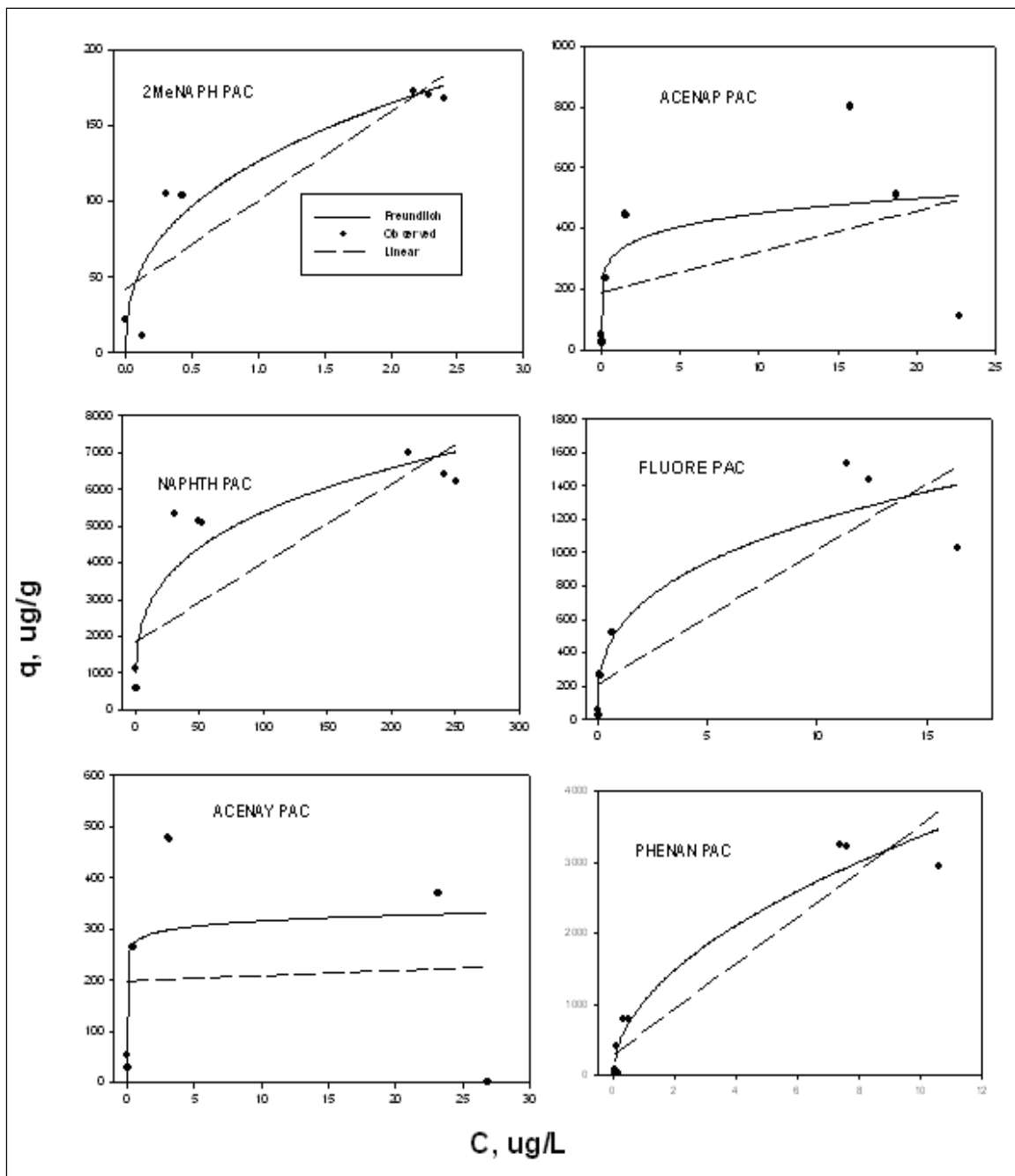


Figure 15. PAC-PAH isotherms (1 of 2).

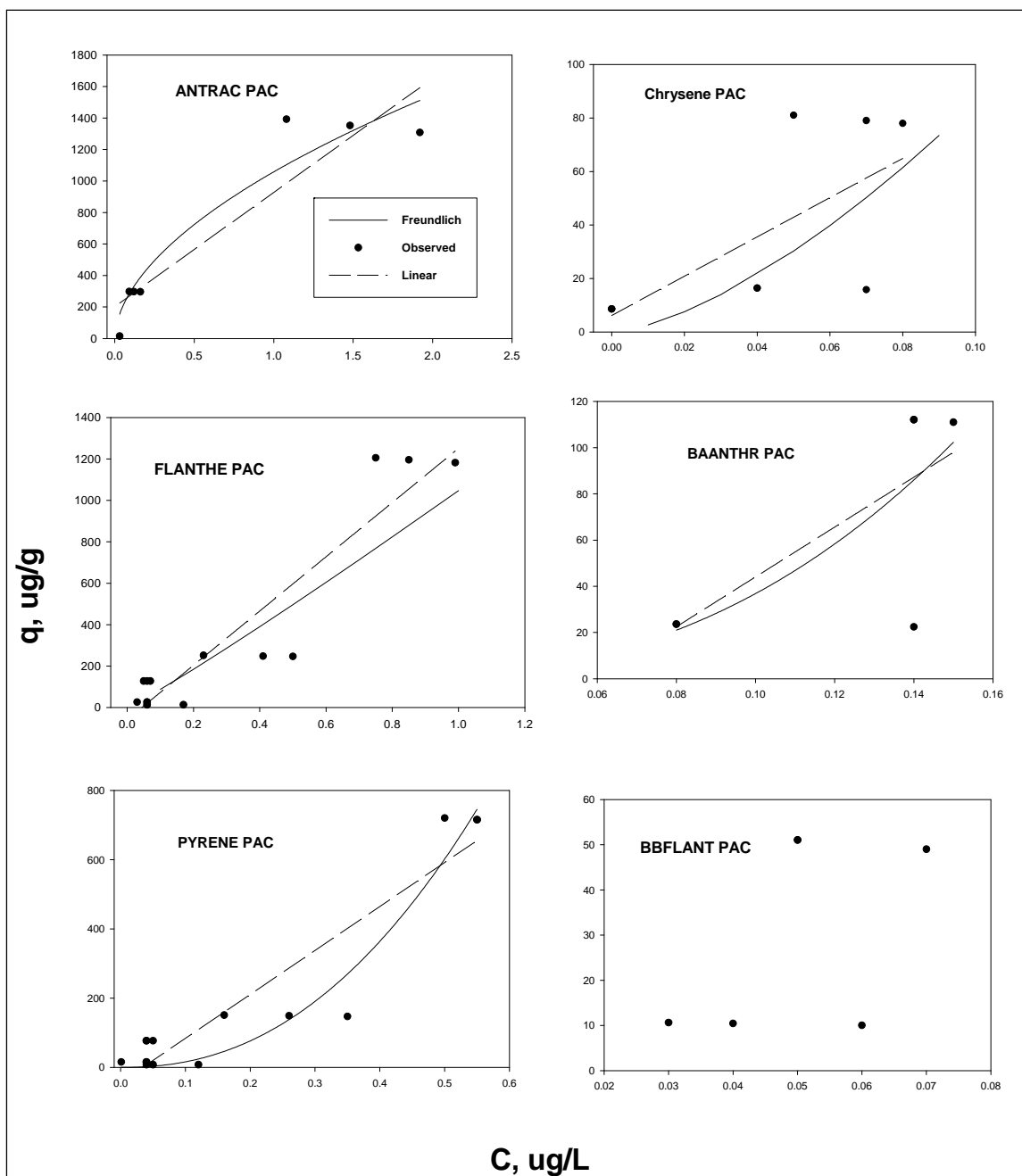


Figure 15. PAC-PAH isotherms (2 of 2).

leach. The other problem was associated with complete removal. At high PAC doses, all the dissolved phase contaminant was adsorbed (100% removal); the only exception was naphthalene. Total removal was especially common for HMW PAHs. An adsorbed concentration can be calculated in this case, but the value calculated is not necessarily the equilibrium value required for isotherm plots. Negative reduction percentages were strictly associated with low PAC dosages. Complete adsorption was strictly associated with high PAC dosages. As a conse-

quence of negative and complete removals, points are missing the lower-left (high PAC dosage) and upper-right (low PAC dosage) sectors of the isotherm plots.

Not shown in Figure 15 are benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. So little of these PAHs desorbed into the simulated effluent that only the two lowest PAC dosages did not remove all of the dissolved contaminant. The benzo(b)fluoranthene scatter plot in part 2 of Figure 15 is an example. In the case of benzo(b)fluoranthene, the starting concentration in the simulated effluent was 0.56 $\mu\text{g/L}$, and after testing with only 0.01 g/L PAC. The dissolved concentration was reduced to a mean value of less than 0.06 $\mu\text{g/L}$ for the three replicates. At higher doses of PAC, all the benzo(b)fluoranthene was removed, except for the 0.05 g/L PAC dose (92% removal). With only two PAC dosages to consider, there is little value in developing plots and fitting equations. The isotherm plot for benzo(a)anthracene in part 2 of Figure 15 is an example. The adsorption data for benzo(a)pyrene, indeno(1,2,3-c,c)pyrene, and benzo(g,h,i)-perylene were similar to that for benzo(b)fluoranthene. The starting concentration of dibenzo(a,h,)anthracene was below the lower reporting limit, although the dissolved concentrations after equilibration with PAC at 0.01 and 0.05 g/L were measurable. In this case, it was impossible to calculate the sorption capacity of PAC for this PAH.

PAH adsorption isotherms for GAC are shown in Figure 16. As was the case for the PAC adsorption isotherms, the points shown are for individual replicates, not means of the replicates. All but one of the plots in part 1 of Figure 16 and all of the plots in part 2 of Figure 16 have all 15 q,C pairs plotted. The only exception was acenaphthylene.

The lines of best fit in Figures 15 and 16 were obtained using the regression wizard in SigmaPlot™ (SPSS, Inc. Chicago, IL). Fitted parameters and statistics are listed in Table 12. Most of the Freundlich fits were obtained using nonlinear regression. In some cases, nonlinear regression yielded extremely poor and unreasonable fits. In these cases, linear regression of $\log q$ onto $\log C$ was used. For some PAC isotherms (HMW PAHs), statistical curve fitting, linear and nonlinear, did not provide the expected Freundlich shape, and the fitted isotherms were concave up, i.e., $n < 1$. The q_0 values in Table 12 have no physical significance; they are simply the y-axis intercept. The linear fits could have been forced through zero, but the

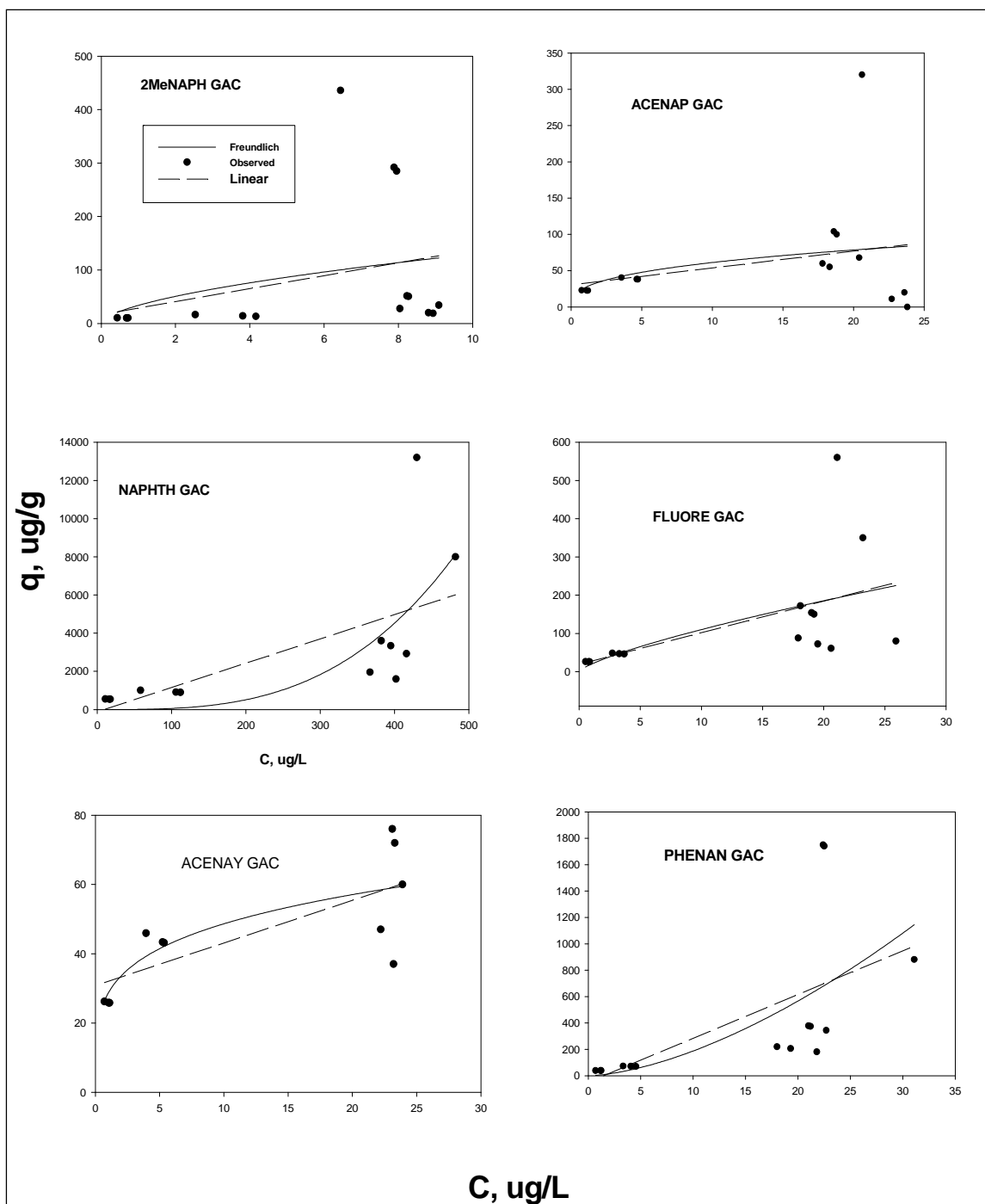


Figure 16. GAC-PAH isotherms (1 of 3).

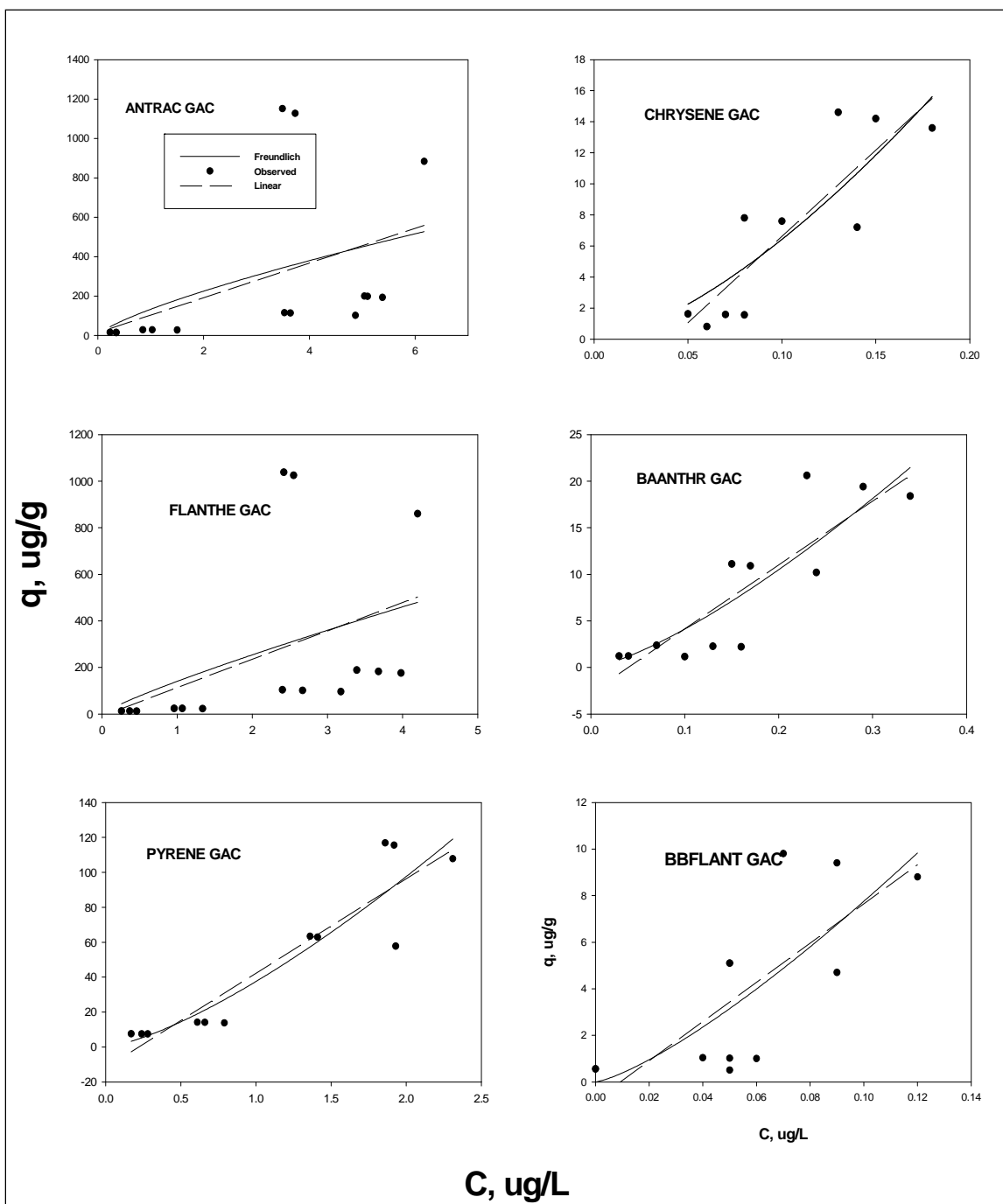


Figure 16. GAC-PAH isotherms (2 of 3).

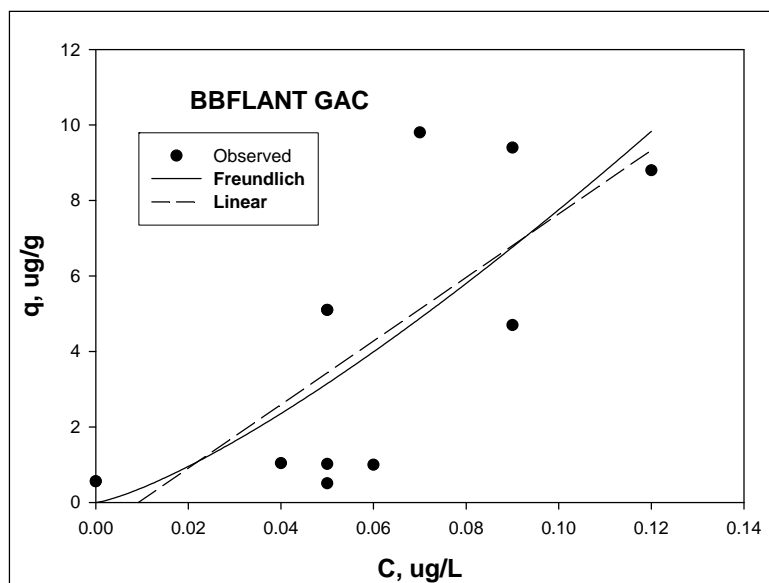


Figure 16. GAC-PAH isotherms (3 of 3).

slopes would have been altered. The slopes for intercept-adjustable linear fits better represent the change in sorbed PAH concentration with respect to change in dissolved PAH concentration than would slopes obtained by forcing the line of best fit through zero.

The Freundlich sorption coefficient (K_f) is an index of the sorption capacity of the sorbent, and the Freundlich exponent (n) denotes the degree of deviation from isotherm linearity. The units of K_f vary nonlinearly with n ; therefore, K_f values derived from sorption isotherms with different n values cannot be directly compared. Activated carbon effectiveness, however, can be compared directly from the plots of percent reduction of PAH concentrations in the simulated IHC effluent versus carbon dosage.

The lower the molecular weight of the PAH, the better the fit provided by the Freundlich equation. Similarly, the higher the molecular weight of the PAH, the better the fit provided by the linear equation. The Freundlich equation provided better fit to the adsorption data for LMW PAHs than did the linear equation. This was especially true for the PAC isotherms. The linear equation fit the PAC adsorption data for the HMW PAHs about as well as (and sometimes better) than the Freundlich equation. In most cases, the linear isotherm equation fit the GAC adsorption data about as well or better than the Freundlich isotherm equation. This was especially true for the HMW PAH isotherms.

Table 12. Fitted isotherm parameters.

PAH	PAC									GAC								
	Freundlich			Linear			Langmuir			Freundlich			Linear			Langmuir		
	K _f	n	r ²	q _o	K _d	r ²	1/ab	1/a	r ²	K _f	n	r ²	q _o	K _d	r ²	1/ab	1/a	r ²
NAPHTH	1423	3.46	0.9194	1827	21.6	0.6736	0.00015	0.00131	0.9919	3.1E!5	0.32	0.5284	!117	12.7	0.4261	0.000176	0.0551	0.2334
2MeNAPH	126	2.62	0.8074	42.3	58.4	0.8074	0.00362	0.00487	0.566	33.9	1.72	0.1011	16.6	12.1	0.0889	0.0193	0.0753	0.1786
ACENAP	319	6.73	0.5613	188	13.5	0.2002	0.00541	-0.00593	0.5836	26.8	2.79	0.0949	30.4	30.4	0.7790	0.0348	-0.0766	0.3125
ACENAY	282	20.7	0.4222	198	1.03	0.0020	0.00267	0.000114	0.9917	28.6	4.34	0.6286	30.8	1.23	0.5619	0.0173	0.0235	0.8277
FLOURE	547	2.96	0.9146	211	79.6	0.7676	0.000758	0.000862	0.9129	19.5	1.33	0.2918	19.0	8.25	0.2937	0.0072	0.0316	0.416
PHENAN	1045	1.97	0.9574	295	323	0.9015	0.000225	0.000867	0.4553	4.76	0.63	0.3636	0.0	33.1	0.3575	0.000671	0.0424	0.052
ANTRAC	1058	1.83	0.9301	204	723	0.8661	0.000246	0.00077	0.0961	133	1.32	0.2112	14.5	81.2	0.2042	-0.00117	0.0295	0.02728
FLANTHE	1047	0.93	0.7745†	58.1	1309	0.8858	-0.00239	0.00316	0.0555	140	1.17	0.1944	-8.95	12.2	0.1923	-0.0061	0.0391	0.2718
PYRENE	2862	0.44	0.9444	!43.2	1270	0.8744	-0.00422	0.00359	0.0451	37.5	0.72	0.8605	!12.0	54.1	0.8539	-0.012	0.0399	0.2713
CHRYSE	2786	0.66	0.1016†	6.14	735	0.4942	-0.00696	0.00238	0.00692	208	0.67	0.7225	-4.5	111	0.7506	-0.209	0.0423	0.14488
BAANTHR	4046	2.04	0.5037†	-63.7	1078	0.5230	-0.209	0.0307	0.4577	92.1	0.74	0.7526	-2.73	68.6	0.7529	-0.079	0.0396	0.0734
BBFLANT	‡	‡	‡	‡	238 ^ξ	‡	-0.00649	0.00300	0.00214	155	0.77	0.5575	!0.041	78.4	0.5402	-0.159	0.0342	0.01872
BKFLANT	‡	‡	‡	‡	227 ^ξ	‡	‡	‡	‡	‡	‡	‡	‡	174 ^ξ	‡	‡	‡	‡
BAPYRE	‡	‡	‡	‡	433 ^ξ	‡	‡	‡	‡	‡	‡	‡	‡	184 ^ξ	‡	‡	‡	‡
!123PYR	‡	‡	‡	‡	34 ^ξ	‡	‡	‡	‡	‡	‡	‡	‡	78 ^ξ	‡	‡	‡	‡
DBAHANT	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡
B-GHI-PY	‡	‡	‡	‡	72 ^ξ	‡	‡	‡	‡	‡‡‡	‡‡‡	‡‡‡	‡‡‡	‡‡‡	‡‡‡	‡	‡	‡

† : from log q versus log C regression

‡ : data inadequate for isotherm analysis

‡‡ : J value for the elutriate

‡‡‡ : complete sorption (below the detection limit in water samples)

^ξ : single point K_dK_d: [g/L]; K_f:[(ug)⁽¹⁻ⁿ⁾ mlⁿ/g]; n: dimensionless, q_o:[μg/g]

The adsorption isotherm data were also plotted to assess the fit of the Langmuir equation to the data. Based on the r^2 value, Langmuir was similar to Freundlich for several of the LMW PAHs on PAC, but was somewhat improved for naphthalene and acenaphthylene. The fit for the HMW PAHs was worse than the Freundlich and the linear fits for PAC. The Langmuir equation provided notably better fit for acenaphthylene on GAC.

Combining isotherm results for multiple compounds was evaluated using the Langmuir equation. Figure 17 illustrates the models for LMW PAHs adsorbed by PAC and GAC. The Langmuir equation fits the PAC data very well ($r^2=0.98$), but r^2 for the GAC was only 0.64. Similar plots drafted for the HMW PAHs yielded poor results.

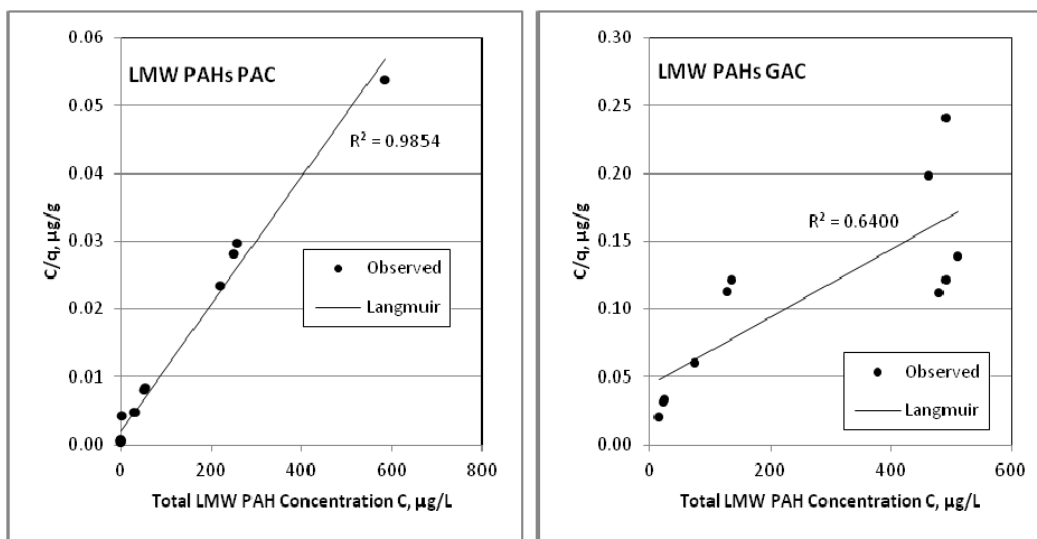


Figure 17. Langmuir equation for LMW PAHs (sum of NAPHTH, 2-MeNAPH, ACENAP, ACENAY, FLUORE, PHENAN, and ANTHRAC).

4.5 VOC adsorption isotherms

Scatter plots of VOC q - C pairs are shown in Figures 18 and 19 for PAC and GAC, respectively. As was the case for the PAH isotherms, the points shown are for individual replicates, not means of the replicates. Of the 15 potential pairs of q and C values for plotting (five PAC dosages in triplicate (Section 4.2.2)), none of the plots in Figures 18 and 19 have all 15 potential q - C pairs, except for the acetone-GAC plot. Again, there were two problems with calculating the q value for a measured C value. In some instances, the dissolved concentration after contact with PAC was higher than the VOC concentration in the simulated effluent prior to contact with PAC. This was especially true at low PAC dosage. The calculated adsorbed concentration in

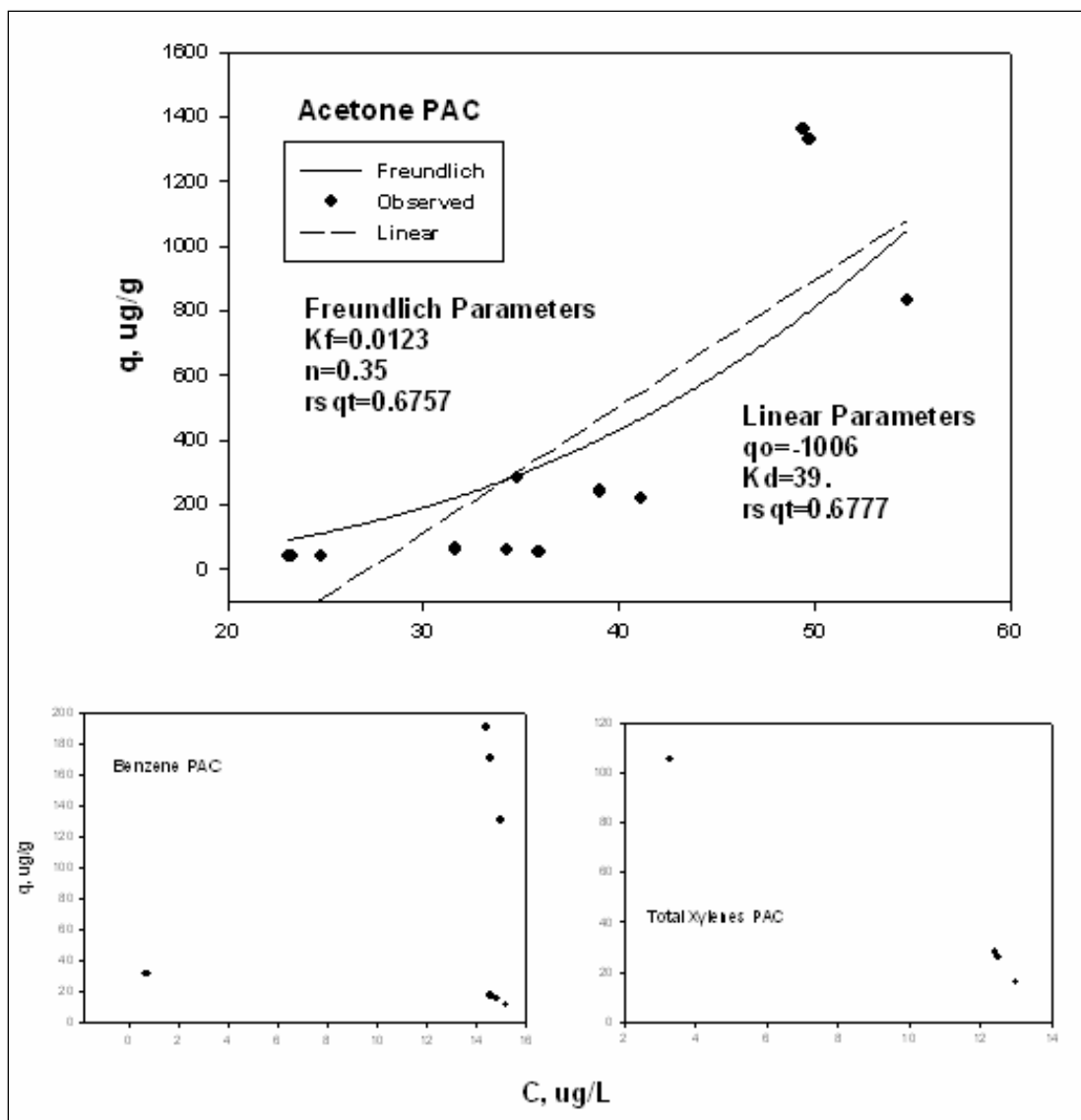


Figure 18. PAC-VOC isotherm plots.

this case is negative (unreasonable). The other problem was associated with complete removal. In some cases, the high PAC doses adsorbed all the dissolved phase VOC (100% removal).

An absence of well-defined adsorption trends for VOCs is evident in Figures 18 and 19. Acetone adsorption to PAC was an exception, and Freundlich and linear isotherm equations were fitted to the acetone PAC adsorption data. The isotherm parameters are included on the plot. Because sorption trends were ill-defined for the other VOCs, isotherm equations were not fitted to the data, and adsorption coefficients were not obtained. The information in Figures 13 and 14 can be used in lieu of adsorption coefficients to estimate removal of VOC from IHC effluent. Methylene

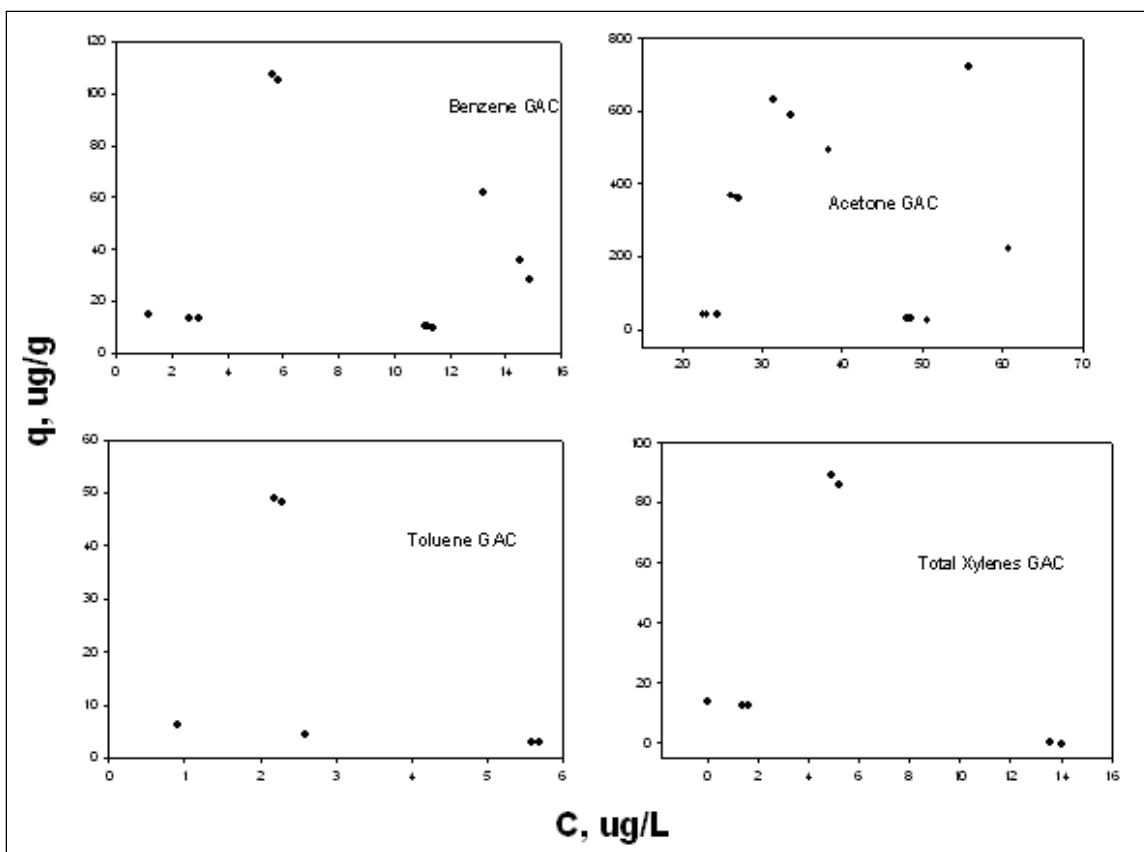


Figure 19. GAC-VOC isotherm plots.

chloride and ethylbenzene scatter plots were not prepared because as previously noted in Section 4.3.3, methylene chloride was not detected in the IHC simulated effluent nor during the adsorption test, and the concentration of ethylbenzene was too low in the simulated IHC effluent and in the effluent after contact with activated carbon for reliable calculation of the amount adsorbed by activated carbon. Toluene adsorption by PAC is not shown because there was only one PAC dose, 0.1 g/L, for which neither 100% nor negative removals (Figure 13) were observed.

4.6 Adsorption isotherm summary

The negative removals in Figures 9 and 10 were a result of simulated effluent PAH concentrations lower than PAH concentrations in the simulated effluent after contact with activated carbon. This occurred at low activated carbon dosages, and probably reflects experimental error associated with PAH analyses. In general, the higher the molecular weight of the PAH, the more effective activated carbon was in reducing PAH concentrations in simulated IHC effluent.

The Freundlich isotherm equation has been traditionally and widely used to characterize adsorption of organic compounds from water by activated carbon. In this study, the Freundlich isotherm equation was good for modeling adsorption of low molecular weight PAHs in simulated IHC effluent to PAC. The Freundlich isotherm equation was not a good model of adsorption of HMW PAHs in simulated IHC effluent to either PAC or GAC. A linear isotherm equation fit the high molecular weight PAH adsorption to PAC and GAC and low molecular weight PAH adsorption to GAC about as well or better than the Freundlich isotherm equation. The Langmuir isotherm equation was an effective model for the combined low molecular weight PAHs treated with PAC.

VOC adsorption by activated carbon was limited, as expected from carbon supplier literature. Low removal of VOCs is generally recognized by activated carbon suppliers, especially removal of acetone, as was the case in this study.

5 Column Settling Tests

5.1 Background

Powdered activated carbon dispersal in the ponded water or dredged material slurry could alter settling and consolidation rates due to the differences in specific gravity, permeability, and flocculation potential between the activated carbon and dredged material solids. There is also a potential that PAC will separate from the settled dredged material solids and remain in suspension. This may aggravate dust problems in the dredged material desiccation phase of CDF operations. Data were therefore needed on the settling properties of dredged material slurry/PAC mixes in order to evaluate the tendency of PAC to float instead of settle with the dredged material solids and to determine PAC-amended dredged material sedimentation rates.

5.2 Methods

Zone settling, compression settling, and flocculent settling characteristics were determined for PAC amended and unamended dredged material. The standard Corps of Engineers column settling test as described in the Corps' Engineer Manual for confined disposal of dredged material (USACE 1987) was used. This test entailed observing the settling behavior of a dredged material slurry in an 8-in.-diam column described in Montgomery (1978). The column (Figure 20) is constructed of acrylic tubing with interchangeable sections and sample ports at 1/2-ft intervals. The interchangeable sections allow for variable length columns; 6 ft in length is the minimum recommended (USACE 1987). Approximately 8 gal of sediment was used to prepare a slurry for testing. Tap water was used to mix the slurries. Figure 21 is a conceptual sketch of zone and compression settling that is measured in a column settling test.

Settling tests were run at initial slurry concentrations of 76.8 g/L w/no PAC, 101.7 g/L w/no PAC, 101.9 g/L w/1% PAC, and 78.6 g/L w/5% PAC. These slurry concentrations were selected to represent the anticipated range of the dredged material influent solids concentrations and range of possible PAC dosages (based on economics). PAC was mixed in after the slurries were prepared. The 101.7 g/L w/no PAC slurry was reused after its compression settling test to create the 101.9 g/L w/1% PAC slurry for

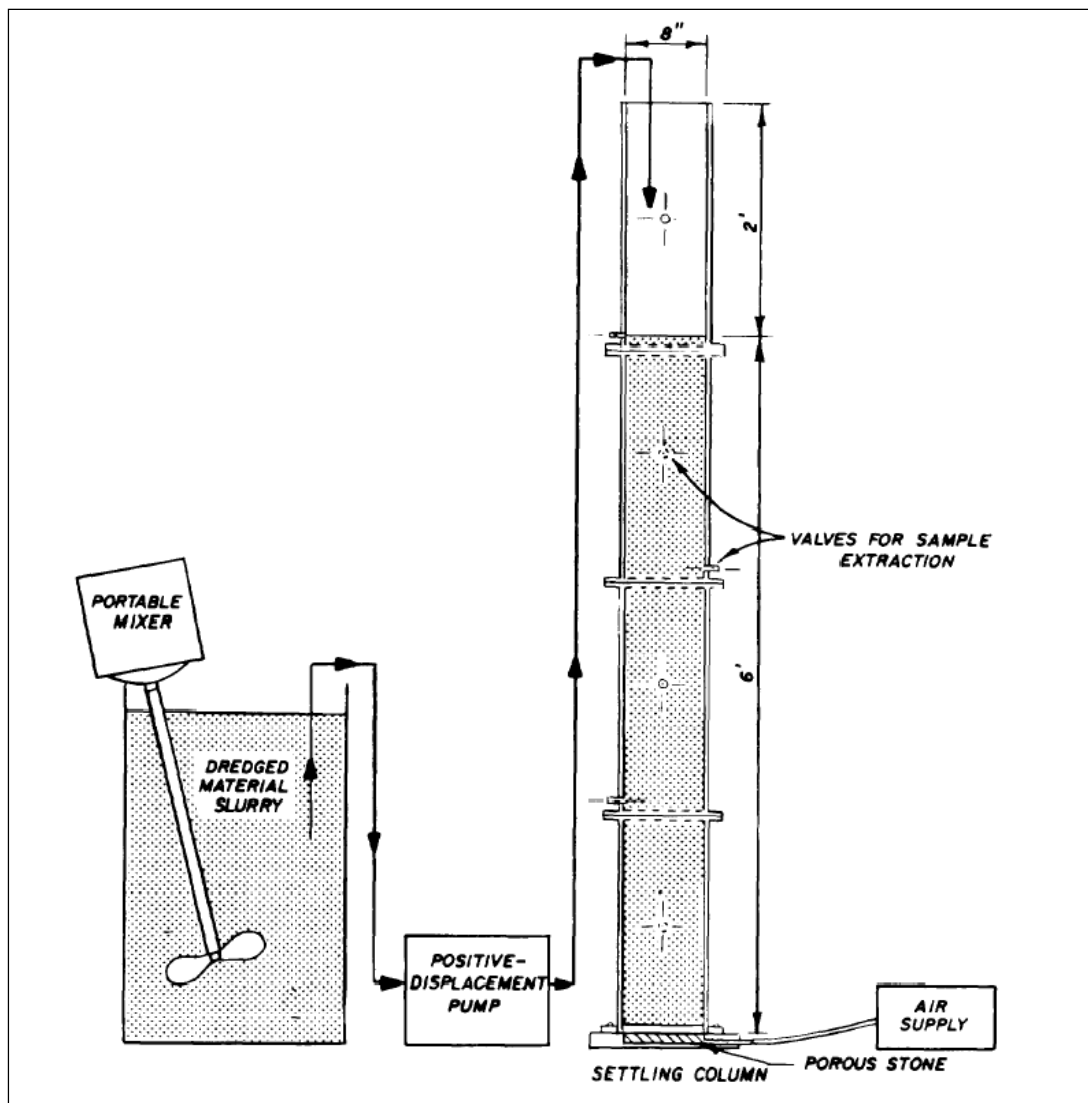


Figure 20. Settling column (after Montgomery (1978)).

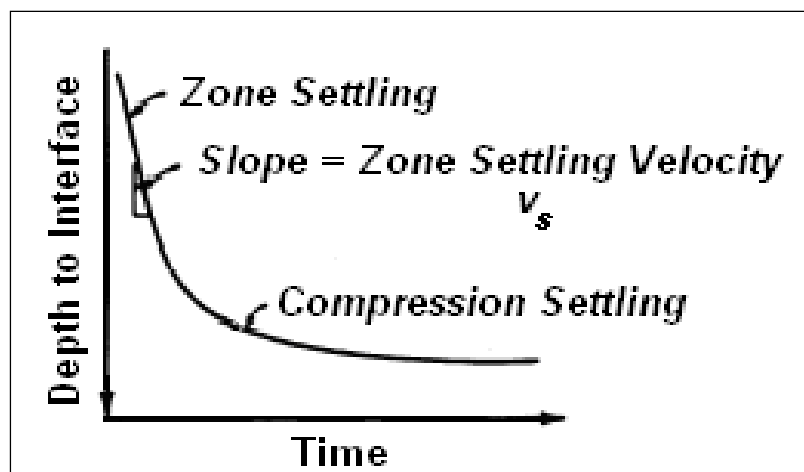


Figure 21. Conceptual sketch of zone and compression settling (from Averett et al. 1988).

testing. Its reuse may have affected the settling due to loss of oil and grease during its initial settling test. Consequently, the tests on slurries 76.8 g/L w/no PAC and 78.6 g/L w/5% PAC were prepared and run at the same time on the same fresh sediment slurry that was divided for a test with PAC and a test without PAC to obtain unbiased results.

Zone settling rates were determined by measuring the height of the liquid-solids interface at various times, and plotting these data as depth-to-interface versus time. The slope of the straight-line portion of the curve shown in Figure 21 is the zone settling velocity. When the settling curve departs from linear, compression settling begins.

Compression settling data were obtained by continuing zone settling tests for a period of 15 days so that a relationship of solids concentration versus time in the compression settling range was obtained. The interface height as a function of time, along with the initial height and solids concentration of the slurry, were used to average solids concentration below the interface as a function of time. These concentrations were plotted against time on a log-log scale to yield a straight line, described by the equation, $C = aT^b$, where C is the average solids concentration, a and b are compression settling constants, and T is time.

Flocculent settling describes the behavior of suspended solids in the clarified supernatant water above the sediment/water interface. Flocculent settling data were needed to evaluate the tendency of PAC to float instead of settle with the dredged material solids. A sample of the supernatant was taken from the uppermost port of the settling column as soon as the settling interface fell below the port far enough to allow sample withdrawal without disturbing the interface. For all tests, this occurred within a few hours of the initiation of the test. Samples were then taken from all ports above the falling interface at time intervals of approximately 2, 4, 6, 12, 24, 48, and 96 hr, continuing to 15 days or until the supernatant suspended solids concentration indicated essentially no further removal of suspended solids through sedimentation. The port samples were analyzed for concentration of total suspended solids and turbidity in the supernatant. Flocculent settling data were analyzed as outlined in Palermo (1986), USACE (1987), and Hayes and Schroeder (1992). Power curves of the suspended solids concentration as a function of depth from the surface were fitted for each sampling time. The curves are of the form $R = R_o + aZ^b$ where R is the percent of initial supernatant suspended solids concentration remaining in

suspension and Z is depth from the water surface. R_o (the percent of initial supernatant suspended solids concentration remaining in suspension at the water surface for the time at which suspended solids were measured below the water surface) and a and b are regression coefficients. Regression coefficients were not displayed since each curve results from only a small number of data points, and the coefficients have little physical significance. In some cases where there were less than three points to plot, linear relationships were fitted to the data.

5.3 Settling column results

5.3.1 Zone and compression settling

Column settling data are tabulated in Appendix C. Zone settling, compression settling, and flocculent settling results for settling with and without PAC are shown in the series of graphs presented below. Figures 22-24 show interface versus time, zone settling, and compression settling curves, respectively, for the 101.7-g/L slurry solids with no PAC. For comparison, Figures 25-27 show interface versus time, zone settling, and compression settling curves, respectively, for 101.9-g/L slurry solids with 1% PAC.

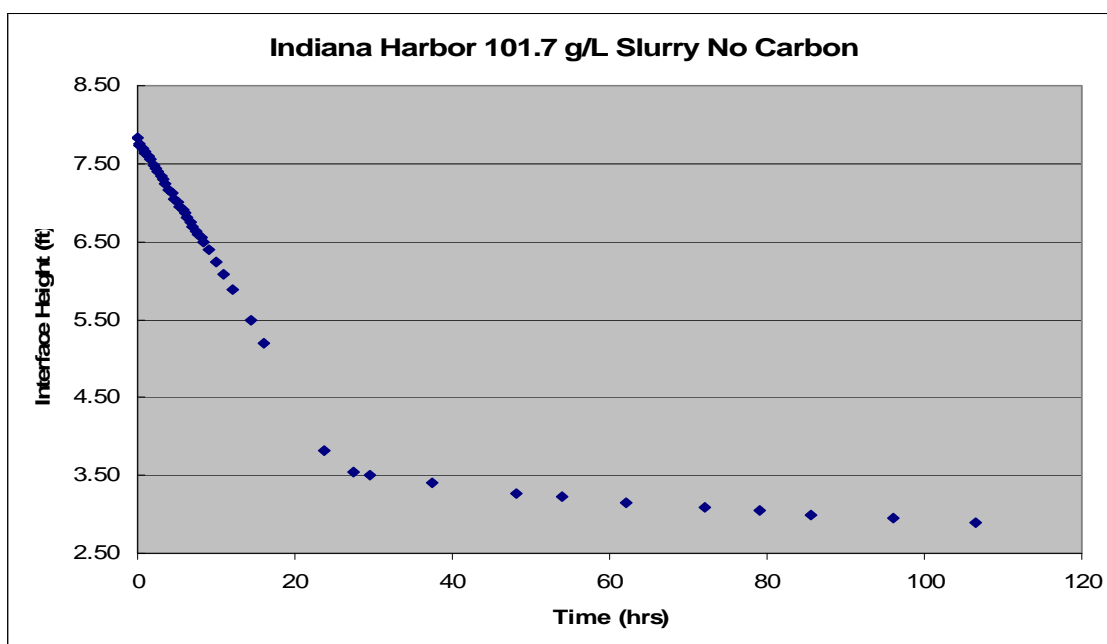


Figure 22. Interface settling curve, 101.7 g/L slurry, no carbon.

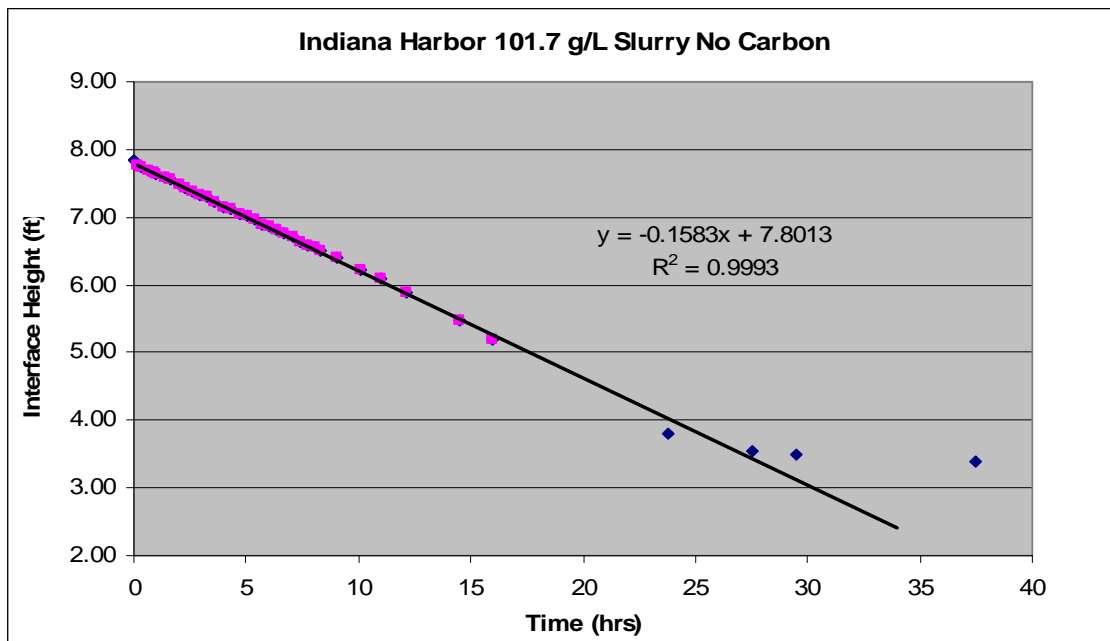


Figure 23. Zone settling curve, 101.7 g/L slurry, no carbon.

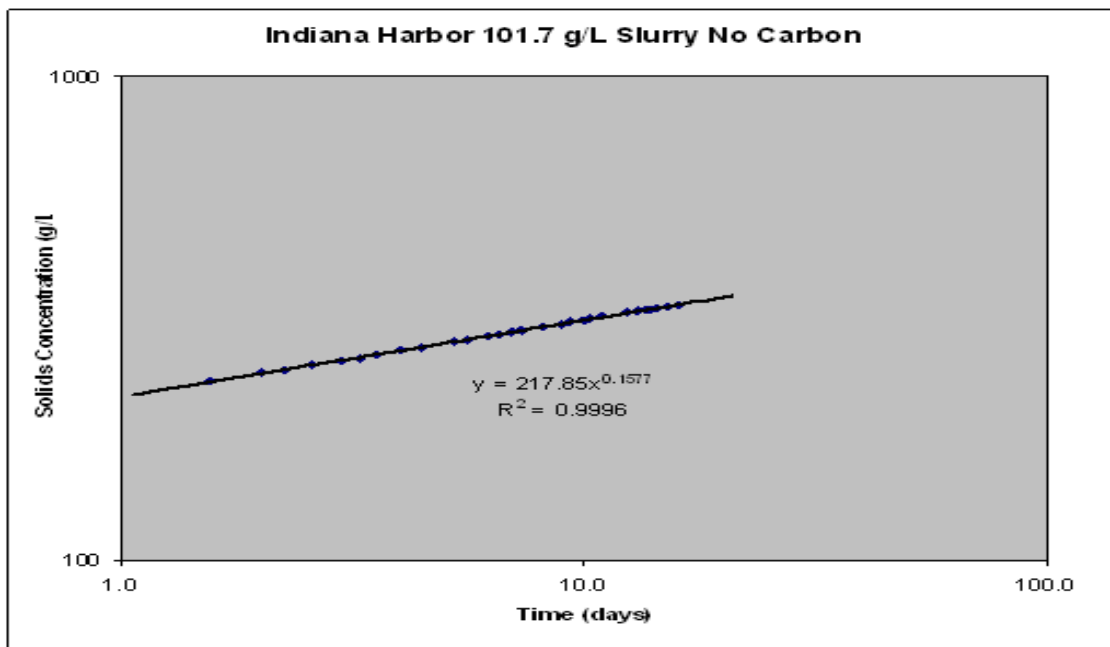


Figure 24. Compression settling curve, 101.7 g/L slurry, no carbon (scale of x-axis and y-axis is log base 10).

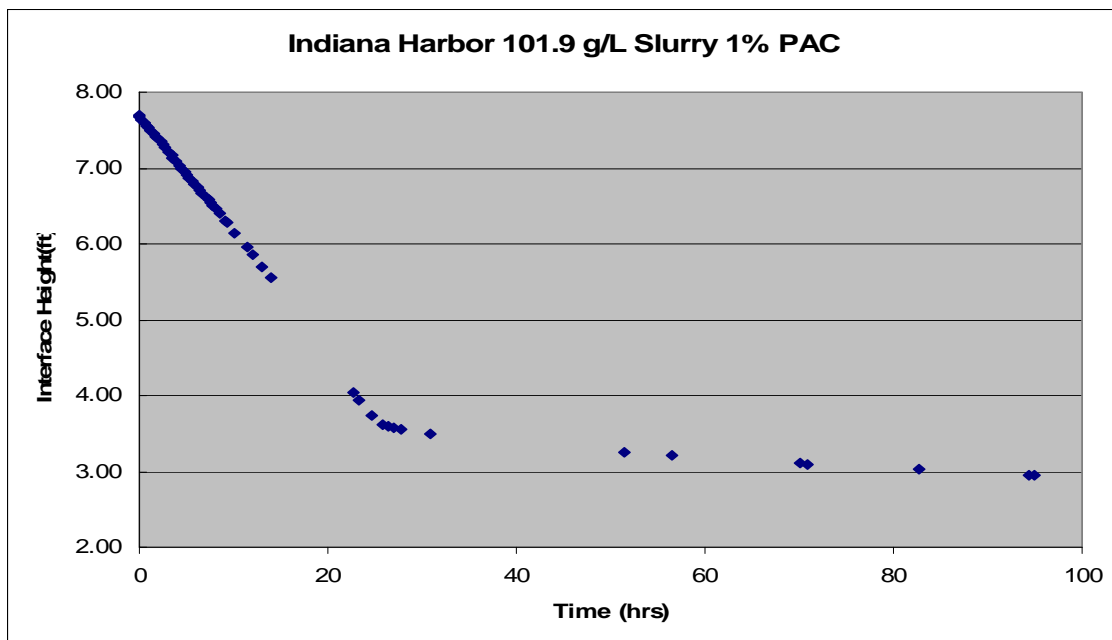


Figure 25. Interface settling curve, 101.9 g/L slurry, 1% PAC.

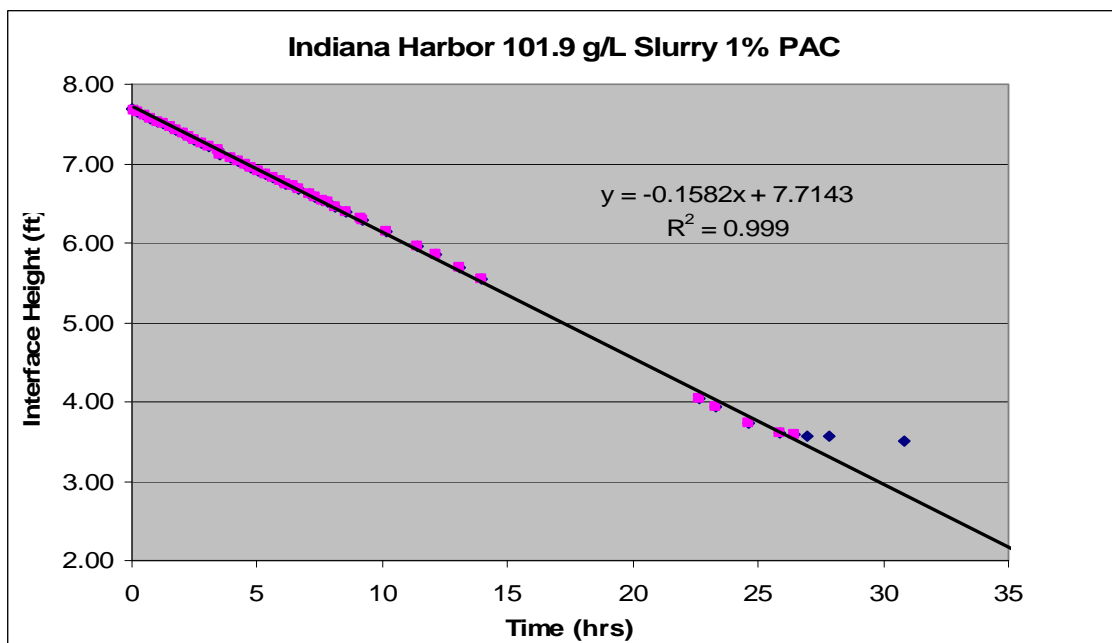


Figure 26. Zone settling curve, 101.9 g/L slurry, 1% PAC.

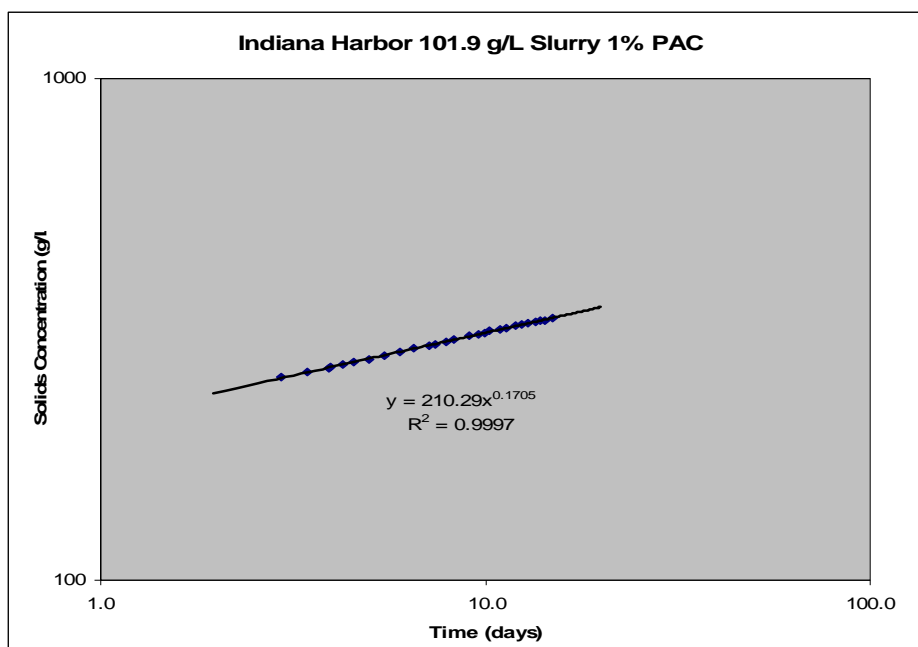


Figure 27. Compression settling curve, 101.9 g/L slurry, 1% PAC (scale of x-axis and y-axis is log base 10).

The zone settling velocity and compression settling results were very similar for the 101.9-g/L solids slurry with PAC and the 101.7-g/L solids slurry without PAC.

Figures 28-30 show interface versus time, zone settling, and compression settling curves, respectively, for the 76.8-g/L slurry solids with no PAC. For comparison, Figures 31-33 show interface versus time, zone settling, and compression settling curves, respectively, for 78.6-g/L slurry solids with 5% PAC.

At the 76.8- to 78.6-g/L slurry solids level, the addition of 5% PAC had little to no effect on zone and compression settling. As expected, the high slurry solids concentration of 101.7g/L had a lower zone settling velocity than the low slurry solids concentration of 76.8 g/L. The R^2 values were greater than 0.98 for zone and compression settling models, indicating good fit to the model equations. Compression settling was similar in all four tests. The predicted solids concentration after 10 days of compression settling ranged from 313 g/L to 324 g/L. Thus, there was very little difference in the densification of the settled solids for two slurry solids starting concentrations with or without PAC. Addition of PAC does not appear to affect zone and compression settling behavior of the dredged material.

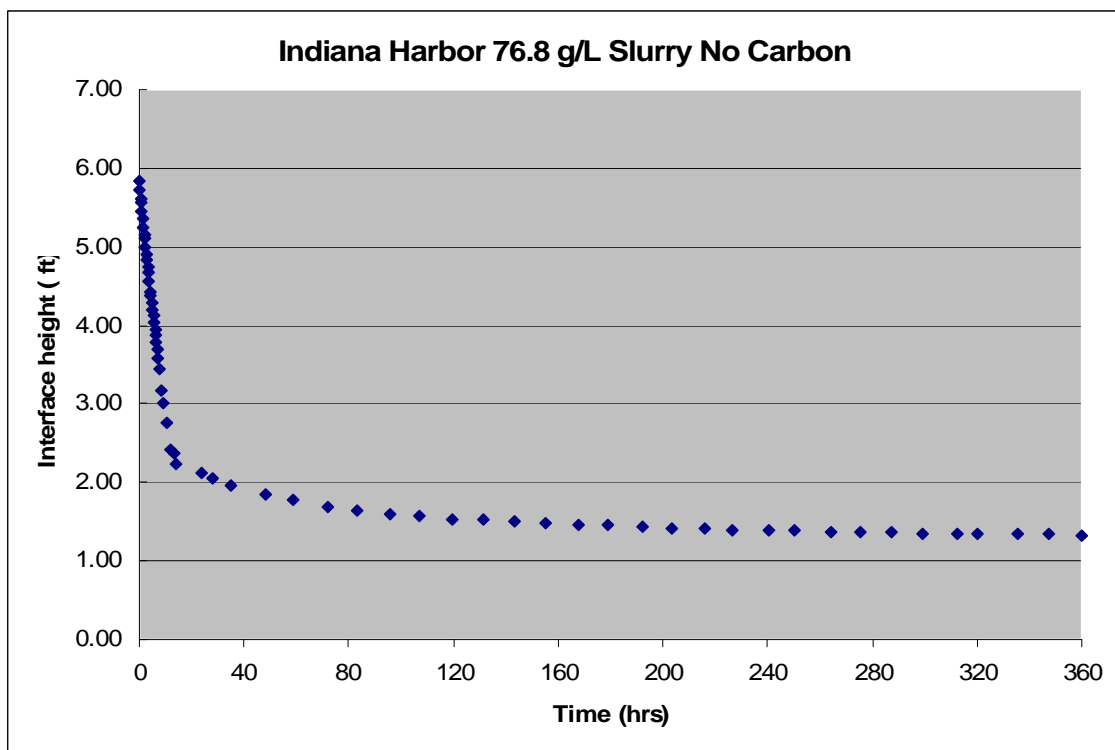


Figure 28. Interface settling curve, 76.8-g/L slurry, no carbon.

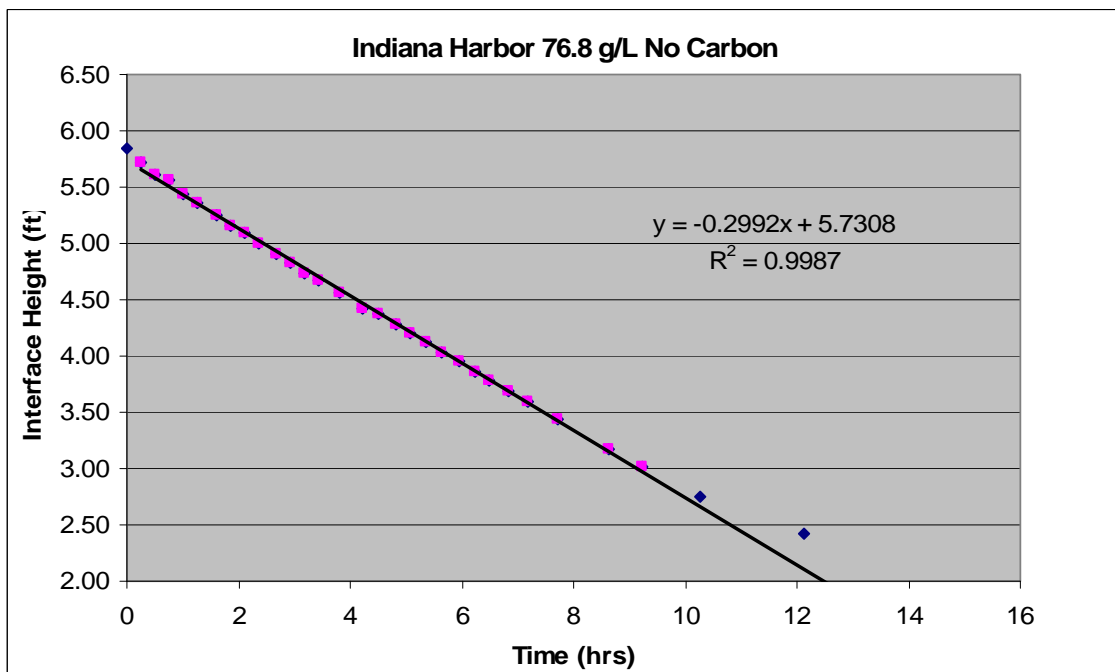


Figure 29. Zone settling curve, 76.8-g/L slurry, no carbon.

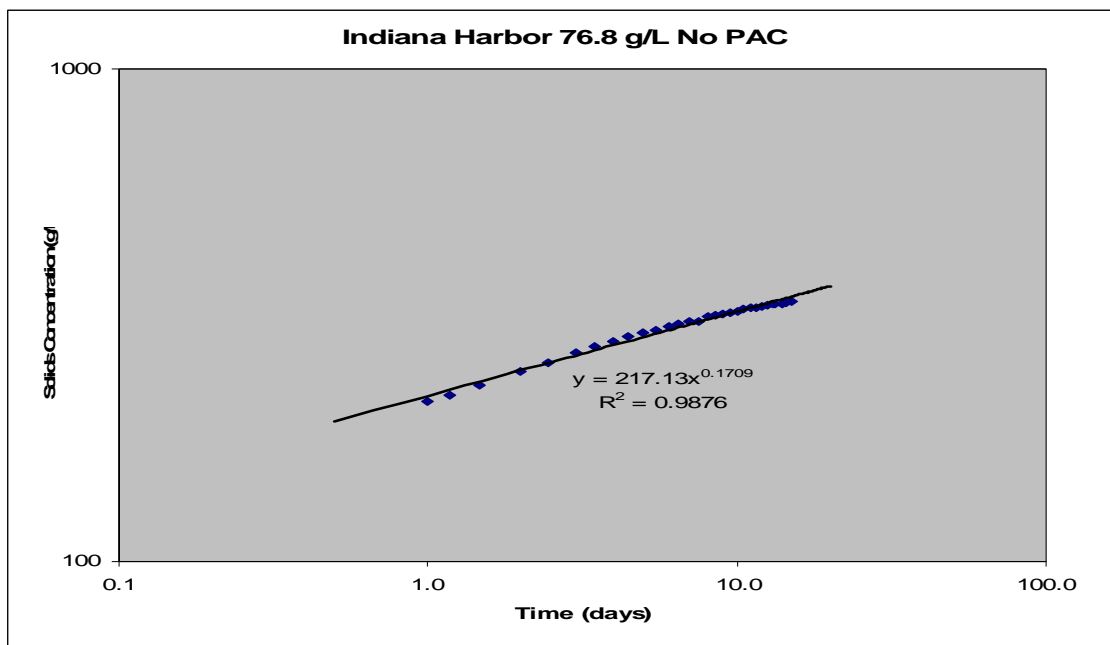


Figure 30. Compression settling curve, 76.8-g/L slurry, no carbon (scale of x-axis and y-axis is log base 10).

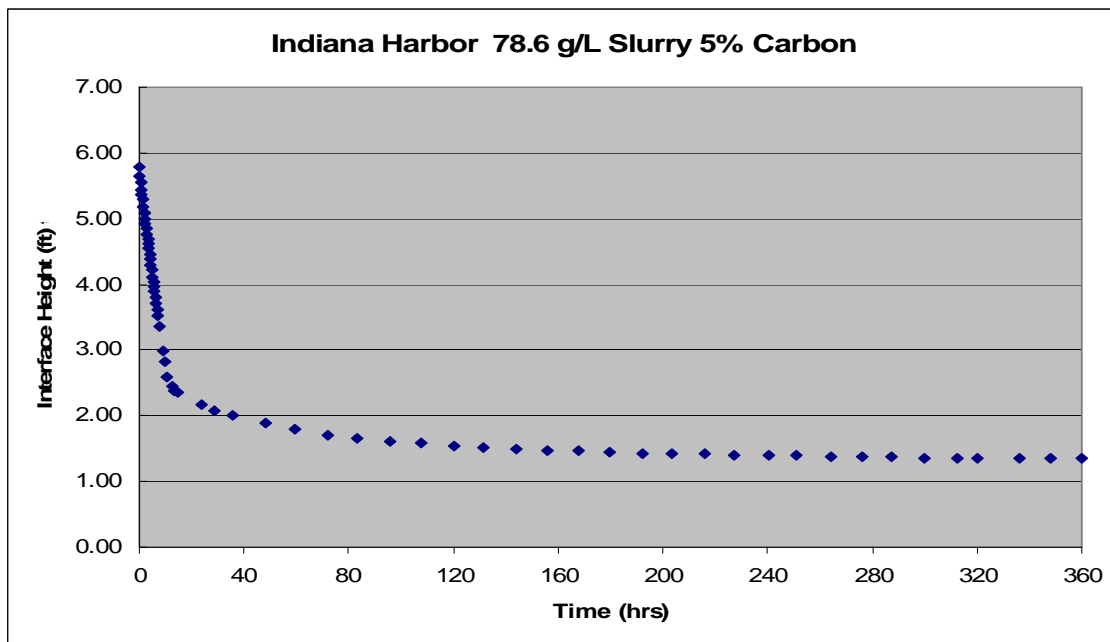


Figure 31. Interface settling curve, 78.6-g/L slurry, 5% carbon.

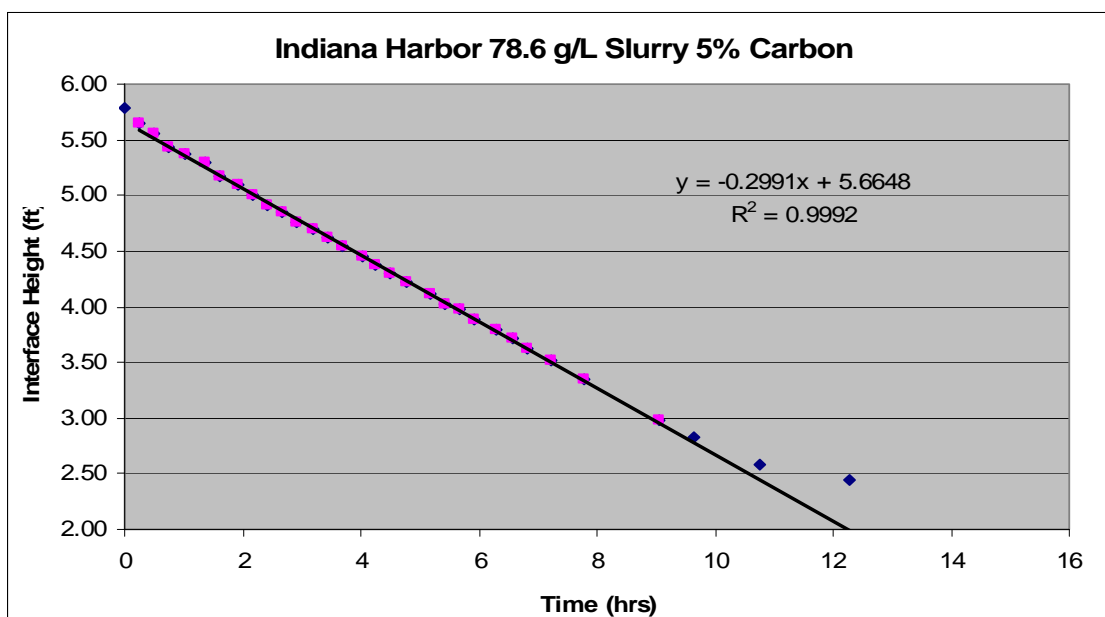


Figure 32. Zone settling curve, 78.6-g/L slurry, 5% PAC.

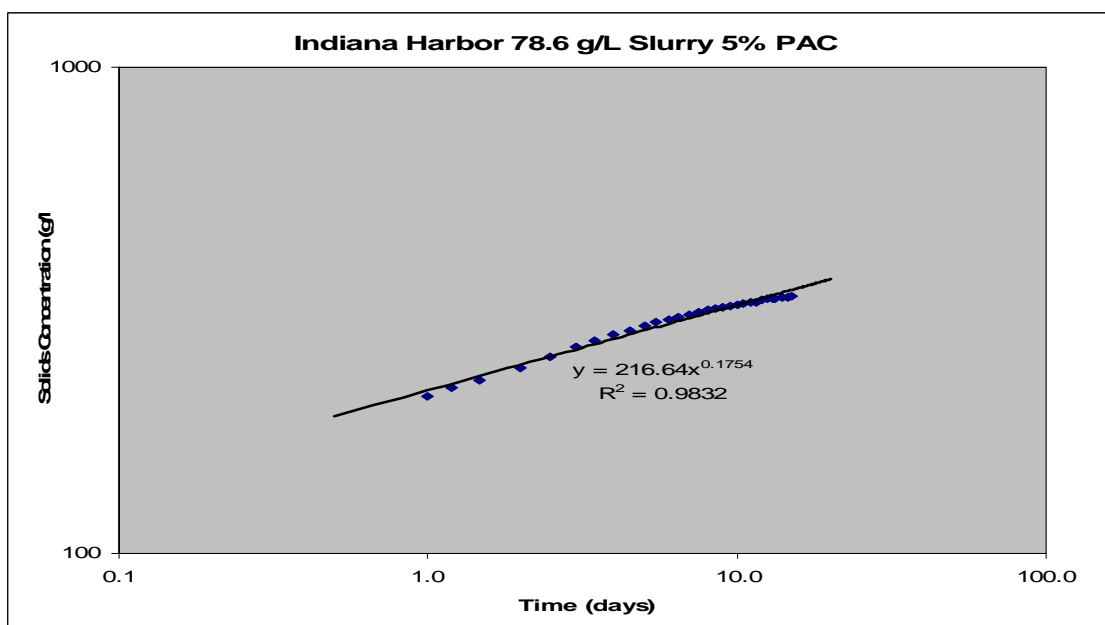
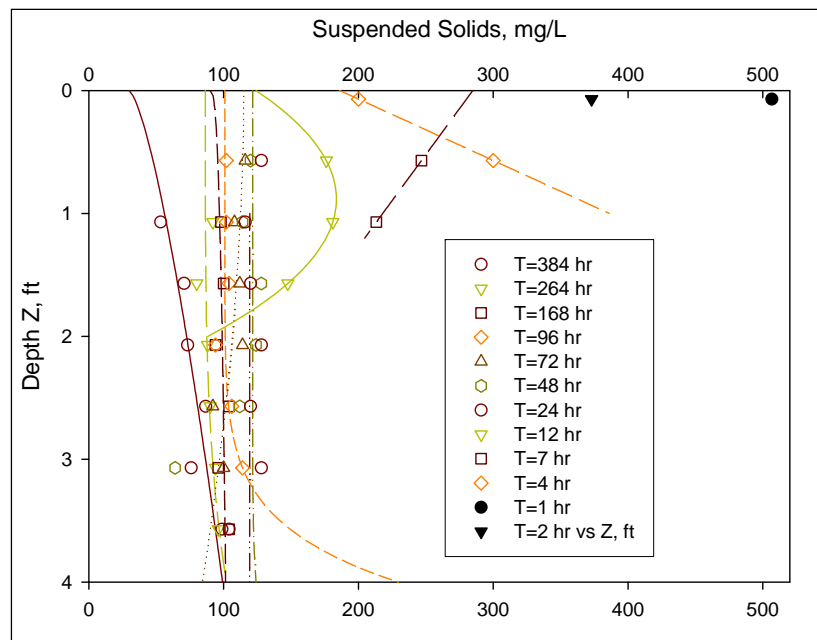


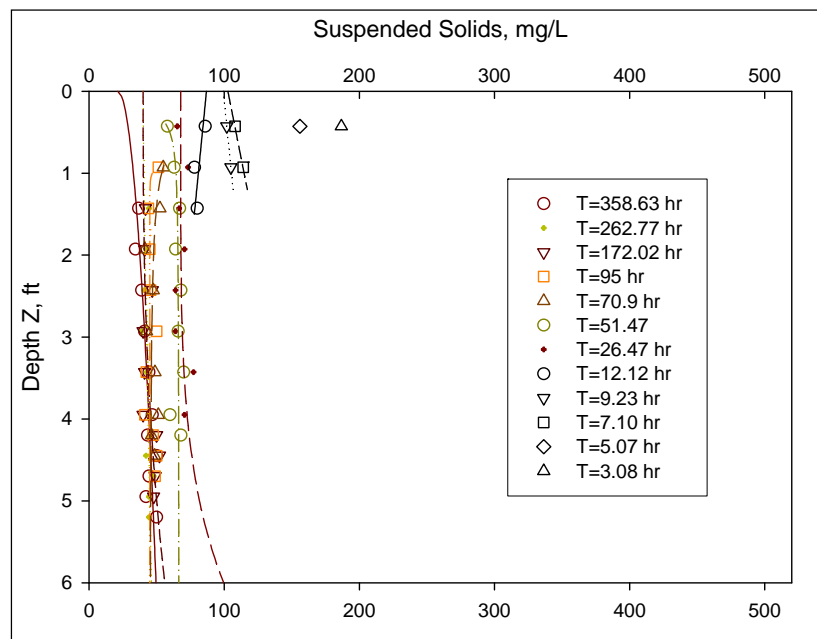
Figure 33. Compression settling curve, 78.6-g/L slurry, 5% PAC (scale of x-axis and y-axis is log base 10).

5.3.2 Flocculent settling

The amount of suspended solids remaining in suspension was plotted versus the depth below the water surface for various sampling times as shown in Figures 34 and 35. Smooth curves were drawn through the data points using the power function given in Section 5.2 or linear or quadratic models as appropriate to the data.

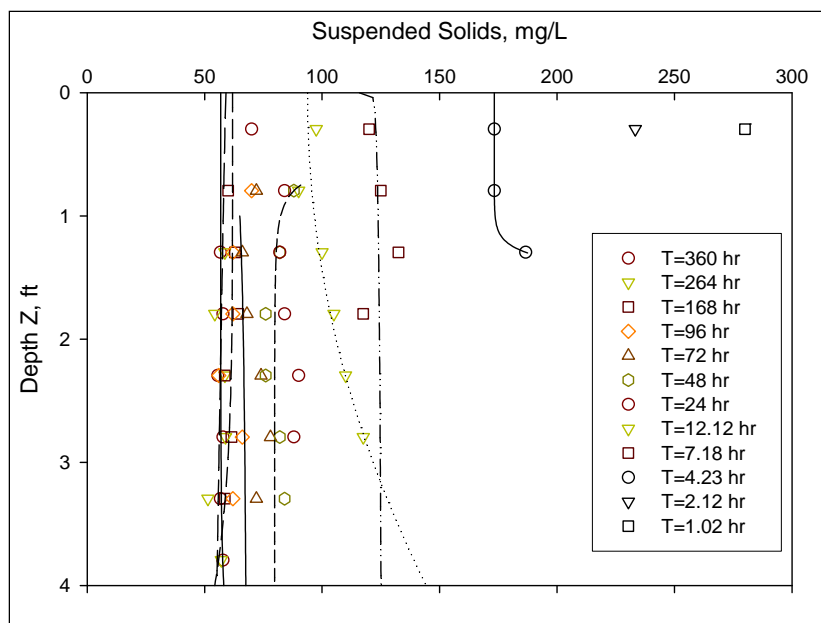


(a)

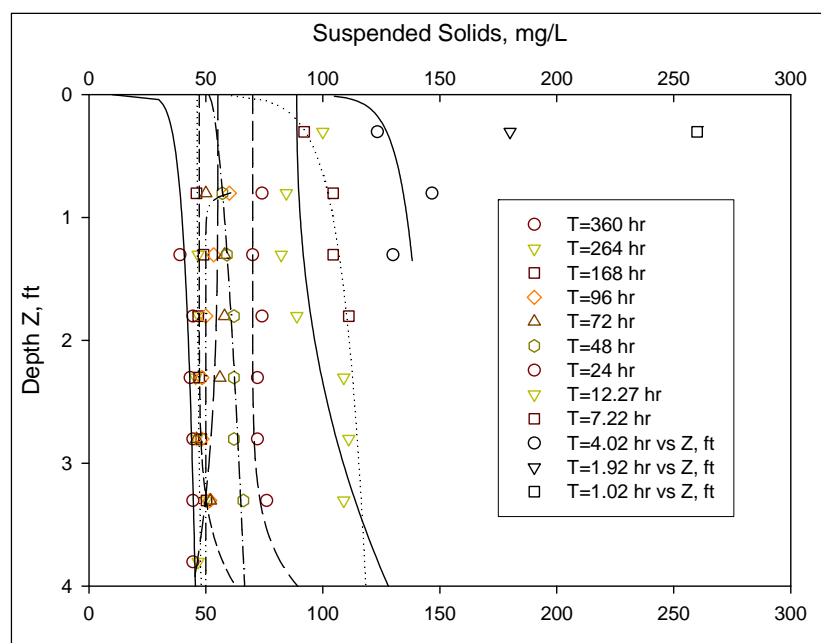


(b)

Figure 34. Flocculent settling curves for 102-g/L dredged material slurry, (a) no PAC, and (b) 1% PAC.



(a)



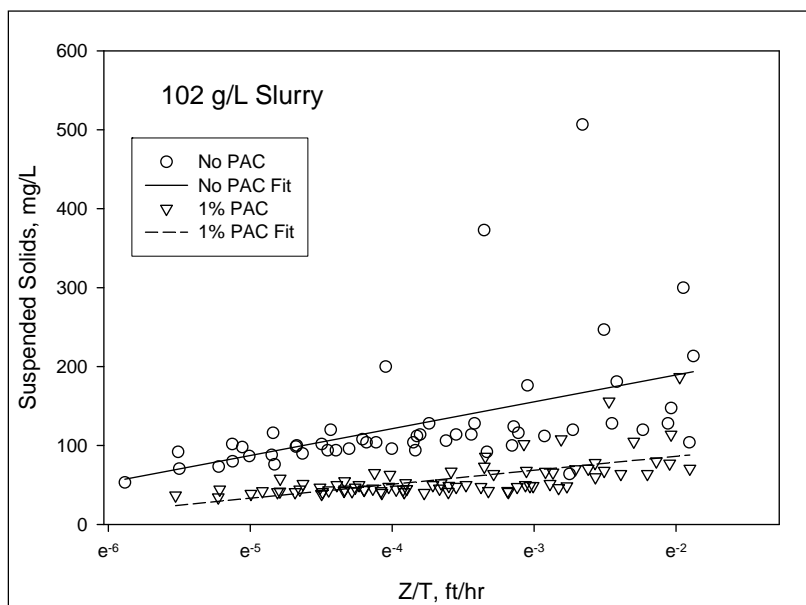
(b)

Figure 35. Flocculent settling curves for 78-g/L dredged material slurry, (a) no PAC, and (b) 5% PAC.

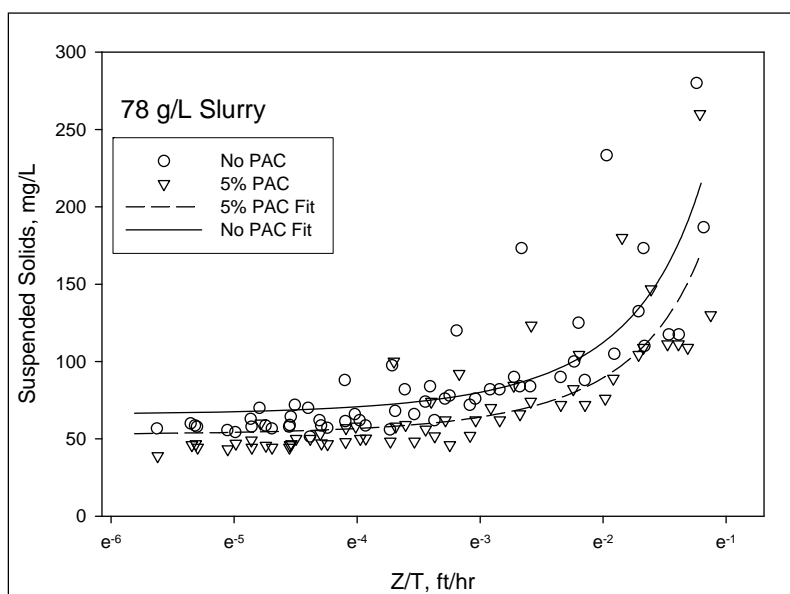
Figure 31 shows that the addition of PAC-assisted flocculent settling for an approximately 102-g/L dredged material slurry. There was also an indication in Figure 32 of assisted flocculent settling for an approximately 78-g/L dredged material slurry, although not as evident as in Figure 31. The greater difference in testing at approximately 102 g/L may have resulted from the

loss of oil and grease in the first test without PAC before the test was repeated following addition of PAC.

In Figure 36 suspended solids concentration has been plotted as a function of the quotient Z/T . The quotient Z/T is not a settling velocity; however, in this form of plot, the entire data set is displayed and treatment effects (with and without PAC) are easier to discern.



(a)



(b)

Figure 36. Suspended solids as a function of depth and time (x-axis is to the log base e, $e=2.718282\dots$).

Figure 36 shows that for a given Z/T , the suspended solids concentration is lower for the PAC-amended slurries than for the unamended slurries. In Figure 36(a), the lines of best fit (linear) show that at high Z/T values (small T), there is a substantial difference (about 50% of the unamended test) in suspended solids concentration between amended and unamended slurries, i.e., PAC reduced the suspended solids concentration at small settling times. The best fit lines in Figure 39(a) also show that as Z/T approaches zero (infinite settling time), the final suspended solids concentration for the PAC-amended slurry will be slightly less than that for the unamended slurry. The differences in predicted final suspended solids concentrations in Figure 36(a) were small and probably not significant.

The difference in lines of best fit in Figure 36(b) was small and may not be significant. PAC addition at the 5% level appears to reduce the suspended solids by about 25% as compared to the results at the same Z/T without carbon addition.

The shape of the lines of best fit in Figures 36(a) and 36(b) was different and may indicate that the flocculent settling in the high solids slurry is hindered relative to the flocculent settling at the lower solids slurry. The expected shape for minimally hindered flocculent settling is “S” shaped. At large Z/T , the suspended solids concentration is large, but cannot exceed the initial slurry concentration and is thus limited. As Z/T approaches infinity, the suspended solids concentration asymptotically approaches the limiting value of the initial slurry concentration. At the other extreme, as Z/T approaches zero, the expected curve asymptotically approaches some constant, maybe zero. Between these limiting values, the curve is S shaped. The suspended solids in Figure 36(a) show no tendency to curve upward as Z/T increases, whereas the data in Figure 36(b) show curvature at high Z/T values. Thus, flocculent settling at the lower slurry solids concentration was less hindered than flocculent settling at the higher slurry solids concentration.

Stray points (those with significant deviation from the fitted lines) occurred at the higher Z/T values and were more pronounced for unamended slurry than for PAC-amended slurry. Stray points were an indication of a disparate floc at the high Z/T values. Thus, PAC addition improved the uniformity of floc development, perhaps by neutralizing the effect of oil and grease on flocculation. Better uniformity of the floc with PAC addition indicated no

PAC separation from the dredged material solids, and therefore no tendency to float.

5.3.3 Column settling summary

Zone settling was improved by PAC addition at the high slurry solids concentration (109 g/L), and PAC addition had no effect on zone settling at the lower slurry solids concentration (78 g/L). There was no evidence of a tendency for PAC to separate from the dredged material solids and float. PAC assisted clarification of the supernatant (flocculent settling results) and did not significantly reduce the ultimate density of the settled solids (compression settling results). These are important findings, which mean that previous design calculations for the IHC CDF are still valid.

6 Contaminant Volatilization Investigations

6.1 Introduction

As discussed in Chapter 1, use of activated carbon to reduce volatile emissions from equalization basins or CDFs receiving IHC dredged material could be achieved by two methods. The first method involves spraying or injecting activated carbon mixed with water over the ponded surface of the CDF or basin. The activated carbon particles will adsorb organic contaminants from the water, consequently reducing dissolved contaminant concentrations and volatile emissions. After the supernatant is decanted and dredged material particles become exposed to the air, the carbon on the surface of the sediment may also adsorb volatile contaminants from the desiccating dredged material. The second method consists of injecting activated carbon into the influent dredged material slurry, which would improve mixing and distribution of the carbon in the carrier water, but may require greater quantities of carbon for the same effectiveness as the first method. This method may provide greater opportunity for controlling volatilization because it will be dispersed within the sediment cake and adsorb organics in the pore water expelled by consolidation processes.

Laboratory experiments were performed to assess the effectiveness of activated carbon in controlling air emissions under these scenarios. Small flux chambers described in USACE (2003) were used to assess losses for the ponded water treatment, a large flux chamber described in Price et al. (2001) was used to assess the efficacy of treating the dredged material slurry, and wind tunnel experiments were used to assess particulate losses from drying sediment (Thibodeaux et al. 2008).

6.2 Laboratory air emission experimental methods

6.2.1 Small flux chamber experiments

A series of bench-scale experiments were conducted using small laboratory flux chambers for measuring emissions from dredged material. The flux chamber is illustrated in Figure 37. It is constructed of two pieces of anodized aluminum, which are sealed together with an O-ring and threaded fasteners to ensure an airtight seal. The bottom section of the chamber is designed to hold a 10-cm-deep layer of sediment with a surface area of 375 cm² (15 x 25 cm). The upper section is grooved to provide an air space

above the sediment for air flow and is designed with channels to distribute air flow uniformly across the sediment surface. A glass window is inserted in the top section of the chamber to allow for visual monitoring of the sediment surface. Figure 38 is a flow diagram for the experimental setup.

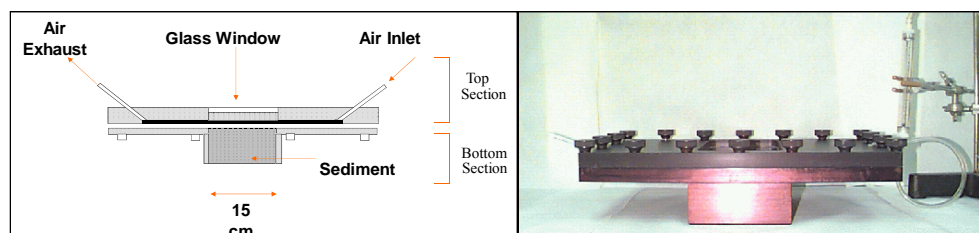


Figure 37. Small laboratory flux chamber.

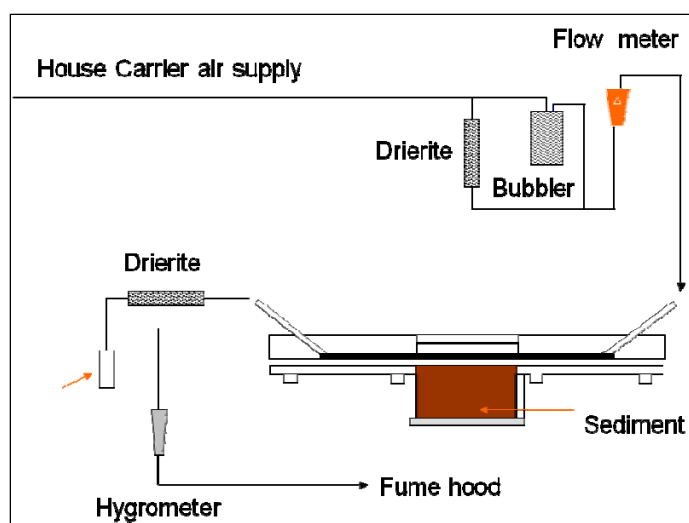


Figure 38. Small flux chamber laboratory schematic diagram.

Experiments were conducted on unamended and PAC-amended simulated settling basin water containing dredged material suspended solids. The unamended test included three dredged material TSS concentrations. The PAC-amended water included three PAC dosages at one dredged material TSS concentration. One wind velocity was used for both experimental conditions. Solids were kept in suspension by stirring to simulate settling basin TSS concentrations. Initial dissolved and particulate VOC and PAH concentrations were determined. VOCs were trapped on Tenax, and PAHs were trapped on XAD-2 resin. Traps were removed from the exit lines at the end of each sampling interval and analyzed.

To maintain consistent starting sediment concentrations, a single bucket of sediment was selected for small flux chamber testing. The sediment was

mixed and analyzed without replication (prior to each experimental run) for VOCs and PAHs in accordance with the methods listed in Table 1.

6.2.1.1 *Ponded water with suspended solids and no PAC*

Unamended dredged material was tested at three TSS concentrations (100, 350, and 700 mg/L). Additionally, flux tests were conducted to compare emissions from 700 mg/L TSS in DDI water versus in elutriate water.

6.2.1.2 *Ponded water with suspended solids and PAC*

Simulated dredged material slurry was prepared by diluting sediment with DDI water to achieve a total solids concentration of 100 g/L. PAC was added to this slurry at concentrations of 0.025, 0.05, and 0.10 g/L. The carbon-sediment mixture was equilibrated by tumbling in zero headspace jars for 15 minutes. The mixture was then settled for 4 hr prior to decanting the supernatant into the flux chamber. The TSS concentration of the supernatant was an average of 990 mg/L. Separate flux chamber experiments were conducted for VOCs and PAHs because the traps used to capture volatile emissions are different.

6.2.1.3 *Ponded water flux – 2 – filtered and PAC added*

An additional amended sediment test evaluated treatment of filtered (0.7- μ m filter) dredged material elutriate with PAC dosages of 0.0001, 0.0005, and 0.001 g/L. A 100-g/L sediment slurry was prepared as above, but was filtered and then loaded into the flux chambers. PAC was then added to the flux chamber.

For each of the small flux chamber tests, a contaminant-specific trap was attached at the flux chamber outlet and collected at regular intervals for a 96-hr sampling time. During each flux experiment, traps were retrieved for analysis to obtain average flux over the following elapsed times: 2 hr, 6 hr, 24 hr, 48 hr, 96 hr, and 144 hr. In addition, initial dissolved and total concentrations of VOCs, PAHs, and TOC were determined for each flux test.

6.2.1.4 *Exposed sediment*

Volatile flux experiments on exposed sediment without and with PAC (5 mg/g) and GAC (5, 10, and 50 mg/g) added to influent slurry were conducted using the small laboratory flux chambers described previously (Figure 37). Exposed sediment is that material remaining in a CDF after

disposal operations have ceased, and the ponded water has been drawn off. VOC and PAH emissions were measured at times of 2, 6, 24, 48, 96, and 168 hr after PAC-amended sediment was added to chambers for each test. The tests simulated volatile emissions from unamended exposed sediment and PAC- and GAC-amended exposed sediment. During settling and densification in the settling basin scenario, adequate contact time between the PAC and dissolved contaminant and dispersal of the PAC in the slurry was expected regardless of dosage. Hence, only one dosage was tested. In the GAC-amended slurry scenario, mixing, contact time, dispersal, and the resulting depression of volatilization may be affected by dosage. Hence, three dosages were evaluated for the GAC test. VOCs were trapped on Tenax, and PAHs were trapped on XAD-2 resin. Traps were removed from the exit lines at the end of each sampling interval and analyzed.

6.2.2 Large flux (resuspension) chamber tests

Air emissions were measured on unamended influent slurry of dredged material as settling took place. This test helped to determine if carrier water released during dredged material settling would contribute significantly to the mass of chemical in the supernatant water in the settling basin and therefore elevate volatile emissions over the level predicted by the tests involving suspended solids only.

The flux chamber is described in Price et al. (2001) and illustrated in Figure 39. The large flux chamber, a cube 50 cm on each side, was constructed of Plexiglas®. The moveable mixing grid consisted of an 8 x 8 grid made of 1.27-cm square aluminum bars with a bar length of 49 cm. The grid was connected to a variable-speed DC motor by a stainless steel shaft, which when attached to a programmable controller, could maintain oscillation frequencies from 60 to 600 rpm. The grid stroke length could be varied from 2 to 12 cm. The chamber lid was sealed with a gasket to produce an airtight fit and fitted with numerous ports to allow for addition of sediment, air supply, exit port, and temperature measurements. Water samples were taken from ports on the side of the chamber.

A measured flow of air was constantly supplied across the top of the water/solids slurry. The outlet air line was split to allow simultaneous trapping of VOCs and PAHs by separate contaminant-specific traps. Volatile contaminants in the downstream air were trapped on XAD-2 resin for PAHs and Tenax for VOCs. Fluxes were initially determined during a quiescent settling period of 10 hr at elapsed times of 2, 6, and 10 hr for PAHs and at elapsed

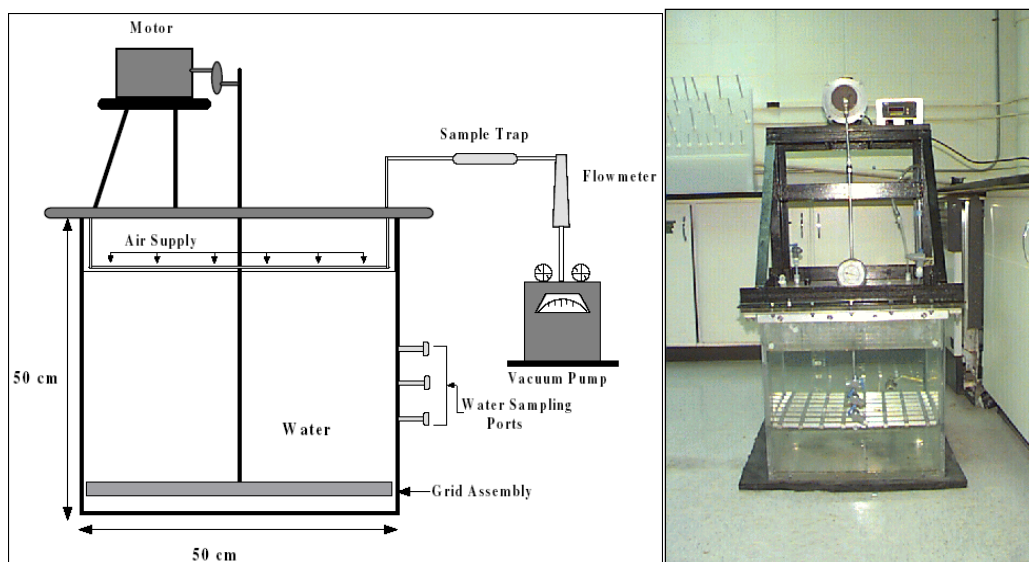


Figure 39. Large flux chamber.

times of 1, 2, 6, and 10 hr for VOCs. Once stirring of the chamber began, fluxes were measured at times of 2, 4, 15, 48, 72, 96, and 144 hr for PAHs and at times of 0.5, 1, 2, 4, 15, 48, 72, 96, and 144 hr for VOCs during each test.

Two (s) buckets of sediment were used for large flux chamber testing. The sediment was mixed and analyzed without replication for volatile organics and PAHs. A sediment/water mixture was prepared at 100 g/L SS concentration. The chamber was loaded with 100 L of this slurry. Once in the chamber, the solids were allowed to settle for 10 hr before mixing began. During the oscillation period, the movable mixing grid mixed the top 30% of the chamber contents at a rate of 25 rpms. Traps were retrieved during the settling period as well as during the mixing period. At the end of each sampling interval, water samples were pulled from side ports on the flux chamber for total suspended solids (TSS) and dissolved VOC and PAH analyses.

6.2.3 Wind tunnel tests

A wind tunnel was used to investigate the potential for a contaminated dust problem to arise after dredged material amended with PAC is dewatered. A suspension of IHC dredged material amended with 1% PAC based on oven dry weight was spread in the wind tunnel and tested for a series of wind speeds as the dredged material PAC mixture dried.

6.2.3.1 Wind tunnel description

The ERDC wind tunnel device is a modified rainfall simulator. The base of the lysimeter, which holds the sediment is 0.46 m (1.5 ft) high, 1.22 m (4 ft) wide, and 4.57 m (15 ft) long (Price et al. 1996). A rectangular tunnel 0.91 m (3 ft) high by 1.22 m (4 ft) wide and 4.57 m (15 ft) long, open at each end, was placed on top the lysimeter. The tunnel contained window panels along one side and on top for both access and to view the inside of the tunnel.

Figure 40 shows a schematic of the tunnel.

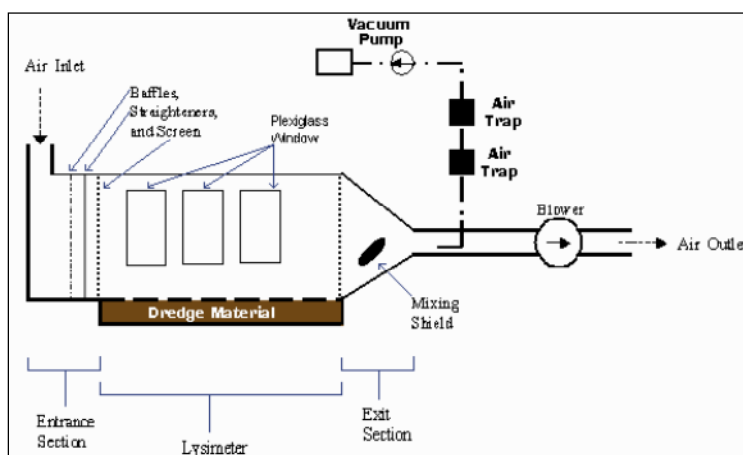


Figure 40. Laboratory wind tunnel setup (Thibodeaux et al. 2008).

Thibodeaux et al. (2008) described the wind tunnel operations as follows.

An 11.2 W (15 hp) blower was used to draw outside air into the wind tunnel via an aluminum duct located outside the building with an opening at 4.57 m (15 ft) above the ground. Once in the entrance zone the air stream is straightened and the flow evenly distributed using a three-part section consisting of a honeycomb, a baffle, and screens. The baffle was made of sheet plywood with teardrop shaped holes to better distribute the inlet airflow arriving in the duct. A thin aluminum sheet of honeycomb cells 1.27 cm (0.5 in.) X 15.2 cm (6 in.) length was added to further straighten the flow. A stack of four wire screens were placed last to further assist in shaping the velocity profile over the lysimeter. Velocity profiles within the tunnel were measured using hotwire and impellor anemometers at locations of 1.22 m (4 ft), 2.44 m (8 ft), and 3.66 m (12 ft) from the entrance screen.

Air sample collection apparatuses were located both within the tunnel section and in the exit section outside of the tunnel. A thin circular metal disk angled at 45 degrees to the wind and placed 30 cm upstream of the sample device was the “mixing body” used to homogenize the air stream (Ruscheweyh 1984) prior to sampling. This gas mixing system has been shown to be very effective in producing uniform concentrations in converging gas streams. The blower unit is located a few feet beyond the air sample port. The air exits at a height of 9.14 m (30 ft) above the ground.

6.2.3.2 *Wind tunnel testing procedure*

The lysimeter was lined with Visqueen, and a French drain was installed in 18 in. of sand for subsurface drainage. Sediment mixed with 1% PAC based on sediment oven dry weight was placed on top of the sand at a depth of 4 to 6 in. Within 10 days after placement, the sediment consolidated to a depth of 2.5 in. and 5 gal of water were drained. Wind at a speed of 4 mph was applied across the surface to facilitate drying. Particulate losses measured during the 100 days of drying amounted to background levels.

Particulate sampling was performed according to “Standard Test Method for Determination of Total Suspended Particulate Matter in the Atmosphere (Hi-Volume Sampler Method),” ASTM D4096-91 (2003). A Staplex Model TFIA hi-volume sampler capable of sampling down to 0.1 μm on 8-in. by 10-in. glass fiber filters was used. Each sample was collected over a 24-hr period with the sampler operating at 55 ft^3/min . air flow rate.

6.2.3.3 *PAH analysis for wind tunnel dust*

Particulates captured by the sampler did not provide sufficient mass for analysis of PAHs. To estimate potential contaminants in dredged material dust, samples were collected from the sediment amended with PAC in the lysimeter. A density separation method using sodium polytungstate (SPT) was used to estimate the contaminant fractions on the sediment and on the PAC. Densities of the materials were:

- | | |
|----------------|-----------|
| • PAC | 0.48 g/mL |
| • IHC sediment | 2.6 g/mL |
| • SPT | 2.5 g/mL |

The SPT separation method involved the following steps:

1. Grind air-dried samples with a mortar and pestle.
2. Place 0.5-g sample in a 30-mL centrifuge tube and add 10 mL of SPT.
3. Sonicate mixture for 30 seconds, then centrifuge at 3500 rpm for 30 min.
4. Vortex samples in tubes, sonicate, and centrifuge three times. The third time centrifuge for 100 min.
5. The separation produces a thick black layer floating on top of the STP (floats) and a dull brown precipitate on the bottom of the tube (sinks).
6. Remove the upper 1 cm of floats, dilute with 10-mL DDI water, and filter through pre-weighed 0.20- μ m polycarbonate filters.
7. Rinse the filters twice with DDI water to remove residual SPT.
8. Air dry the filters and extract with a 50:50 methylene chloride:acetone mixture while sonicating 18 hr at room temperature.
9. Filter through 0.45- μ m filter and concentrate to 3 ml for PAH analysis.
10. Repeat steps 6-9 for the sinks.

The particulate separation and analysis procedure was performed for particles on the surface of the PAC-amended sediment in the lysimeter, for a sample total depth of the PAC-amended sediment in the lysimeter, and for a sample of unamended IHC sediment.

6.2.4 Chemical analytical methods for volatilization experiments

Methods of analysis for VOCs, PAHs, and TOC in sediment are summarized in Table 1. Methods of analysis for these compounds in water are summarized in Table 10. Table 13 lists the methods used for analysis of the air traps used in the volatilization experiments.

The trap for PAHs was an XAD-2 resin (Orbo 44, Supelco, Bellefonte, PA). The XAD-2 resin was extracted with 10 ml of solvent mixture (50% methylene chloride, 46% hexane, 4% acetonitrile) and brought down to 2 ml for analysis as provided in USEPA SW-846 Method 8260B (USEPA 1996).

Tenax TA (35/60) (Orbo 402, Supelco, Bellefonte, PA) was used to trap VOCs. The Tenax tubes were cut and the packing from the front section (Bed A, 100 mg) was placed into a desorption tube that was used with the Gerstel Thermal Desorption System. The tube, including the Bed A packing materials, was spiked with two internal standards added at the ECB laboratory to monitor desorption efficiency and was heated to 280 °C to quantitatively transfer analytes to a cooled injection gas chromatography injection system at -40 °C. Once the analytes were transferred, the injection port was heated to 240 °C and analyte separation occurred on an HP-624

Table 13. Laboratory reporting limits (LRLs) and analyte methods.

Analyte	Matrix	ECB LRL	Extraction Method ¹	Analyte Method ¹
VOCs	Solids ^{2,3}	1.0 ug/g	5035	8260B
	Water ³	2.0 ug/L	5030B	8260B
	Air Traps	1 – 5 ng on column	NIOSH 5506 ⁴	8260B
PAHs	Solids ²	170 ug/kg	3545	8270C
	Water	0.10 ug/L	3510C	8270C
	Air Traps	0.10 ug/L in column extract	Modified NIOSH 5515 ⁵	8270C
TOC	Solids	0.25 g/kg	Not Applicable	9060
	Water	0.25 mg/L	Not Applicable	9060

¹ Method numbers refer to SW-846 (USEPA 1996).

² LRL is based on 100% solids. Dredged material containing moisture will raise the LRL.

³ Except for acetone, which is 10 ug/g for solids and 25 ug/L for water.

⁴ Tube packing material thermally desorbed and analyzed via GC.

⁵ Traps extracted with a 10-ml mixture of 50% methylene chloride, 46% hexane, 4% acetonitrile.

column (25-m length, 0.20-mm internal diameter, 12- μ film thickness) in the oven of an Agilent 6890 Series II gas chromatograph. Analytes were detected on an Agilent 5972 Mass Selective Detector. If analytes were detected in Bed A, then the back section of the Orbo tube (Bed B, 50-mg) was analyzed in the same manner as described above to ensure breakthrough had not occurred.

6.2.5 Experimental description summary

The various tests performed to evaluate activated carbon control of volatile contaminants from IHC sediment are summarized in Table 14.

6.3 Laboratory volatilization test results

6.3.1 Small flux chamber with unamended sediment

Volatilization from unamended IHC sediment was investigated using the small flux chamber as described above. The volatile releases in terms of flux (mass/area/time) are illustrated in Figures 41 and 42 for detectable PAHs. The graphs on the left show the differences for the three TSS concentrations in elutriate, and the graphs on the right show the differences in 700 mg/L TSS in elutriate vs. 700 mg/L TSS in distilled-deionized (DDI) water. Contaminant fluxes were one or two orders of magnitude greater for the

Table 14. Volatilization experimental methods summary.

Test No.	Test Description/Purpose	Test Chamber			Analytes		Solids Concentration		Carbon Doses	
		Small	Large	Wnd Tnl	PAH	VOC	Initial TS (g/L)	TSS (mg/L)	PAC (g/L)	GAC (mg/g)
1	Sediment slurry unamended	x			x		100	100	0	
2	Sediment slurry unamended	x			x		100	350	0	
3	Sediment slurry unamended	x			x		100	700	0	
4	Sediment slurry unamended (DDI)	x			x		100	700	0	
5	Sediment slurry unamended	x				x	100	100	0	
6	Sediment slurry unamended	x				x	100	350	0	
7	Sediment slurry unamended	x				x	100	700	0	
8	Sediment slurry unamended (DDI)	x				x	100	700	0	
9	Resuspended sediment slurry		x		x		100	1670	0	
10	Resuspended sediment slurry		x			x	100	NA		
11	Sediment slurry amended I	x			x		100	1090	0.025	
12	Sediment slurry amended I	x			x		100	860	0.05	
13	Sediment slurry amended I	x			x		100	1020	0.1	
14	Sediment slurry amended I	x				x	100	1290	0.025	
15	Sediment slurry amended I	x				x	100	1130	0.05	
16	Sediment slurry amended I	x				x	100	1110	0.1	
17	Sediment slurry amended II	x			x		100	0	0.0001	
18	Sediment slurry amended II	x			x		100	0	0.0005	
19	Sediment slurry amended II	x			x		100	0	0.001	
20	Sediment slurry amended II	x				x	100	0	0.0001	

Test No.	Test Description/Purpose	Test Chamber			Analytes		Solids Concentration		Carbon Doses	
		Small	Large	Wnd Tnl	PAH	VOC	Initial TS (g/L)	TSS (mg/L)	PAC (g/L)	GAC (mg/g)
21	Sediment slurry amended II	x				x	100	0	0.0005	
22	Sediment slurry amended II	x				x	100	0	0.001	
23	Exposed sediment unamended	x			x		560		0	
24	Exposed sediment unamended	x				x	560		0	
25	Exposed sediment amended	x			x		490		5 mg/g	
26	Exposed sediment amended	x			x		490			5
27	Exposed sediment amended	x			x		490			10
28	Exposed sediment amended	x			x		490			50
29	Wind Tunnel Test			x	x		>560		10 mg/g	

lower molecular weight PAHs (naphthalene, methylnaphthalene, acenaphthalene, and acenaphthene) in Figure 41 compared to the higher molecular weight PAHs in Figure 42. PAHs with molecular weights greater than pyrene (202 g/g-mole) (see Table 2) were less than detection limits for all the emission samples.

The release rate for the naphthalene compounds decreased rapidly during the first 24 hr, whereas the higher molecular weight compounds (pyrene and fluoranthene) showed emissions for the entire sampling period (96 hr). Generally, emissions were greatest for the highest TSS concentration (700 mg/L).

Differences in flux were observed for the elutriate-sediment mixtures versus DDI-sediment mixtures. For the lower molecular weight compounds in Figure 41, releases were greater for the elutriate mixtures, but the opposite was observed for the higher molecular compounds in Figure 42.

Flux estimates based on small flux chamber experiments for volatile organic compounds with time and TSS concentration are illustrated in Figure 43. The initial observations were generally greater during the first one or two

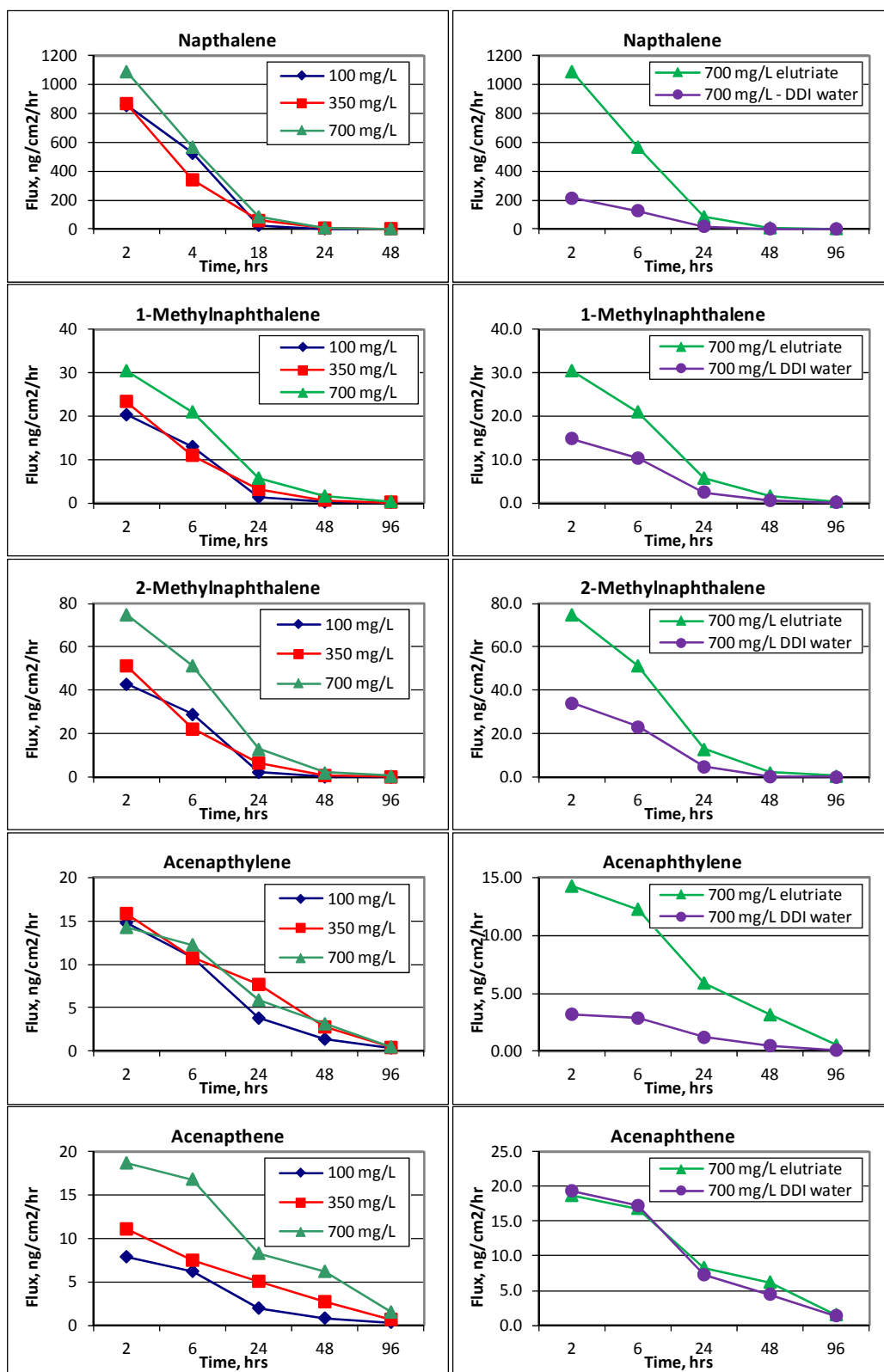


Figure 41. Naphthalene, 1-methylnaphthalene, 2 methylnaphthalene, acenaphthylene, and acenaphthene flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).

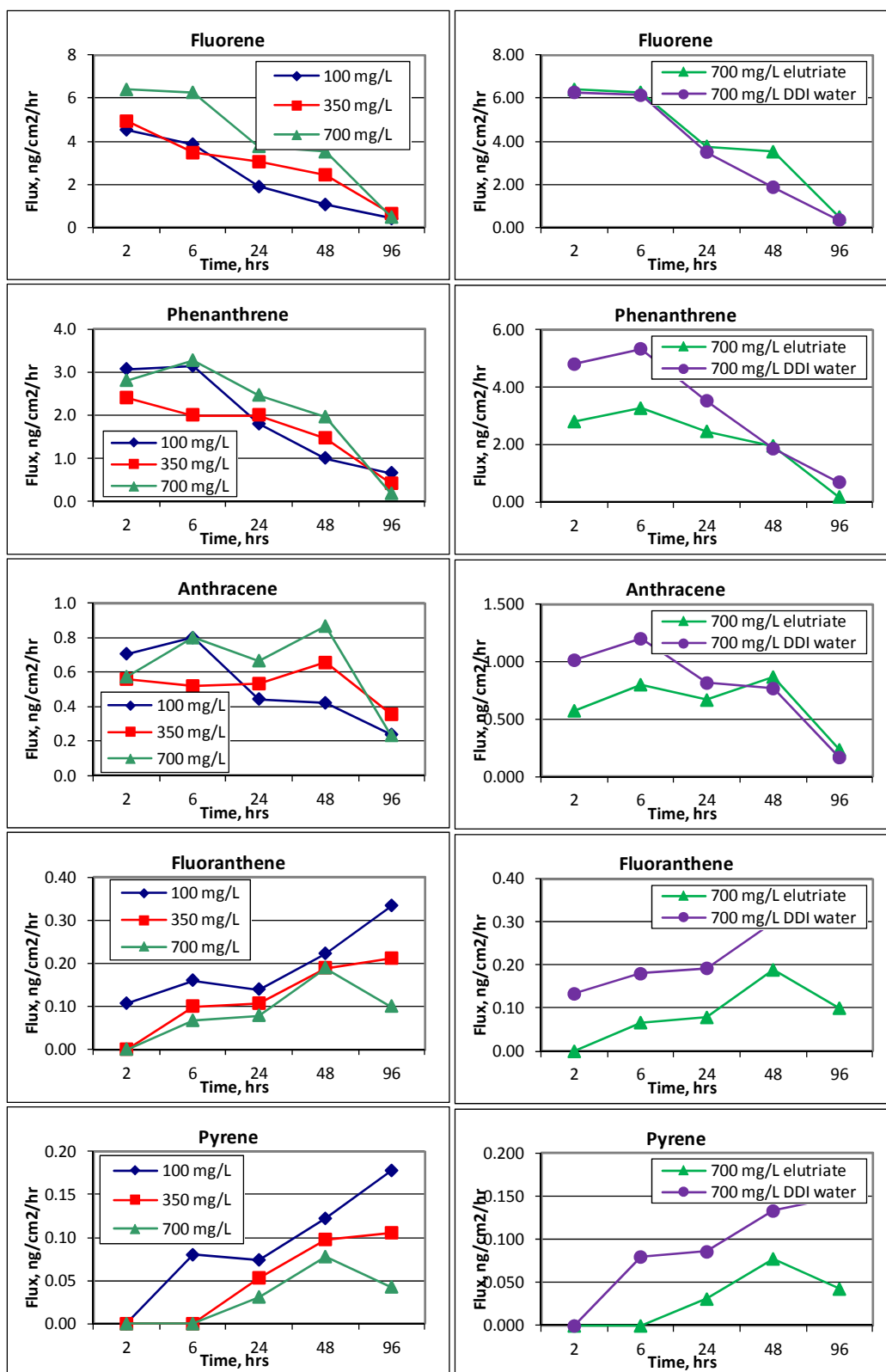


Figure 42. Fluorene, phenanthrene, anthracene, fluoranthene, and pyrene flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).

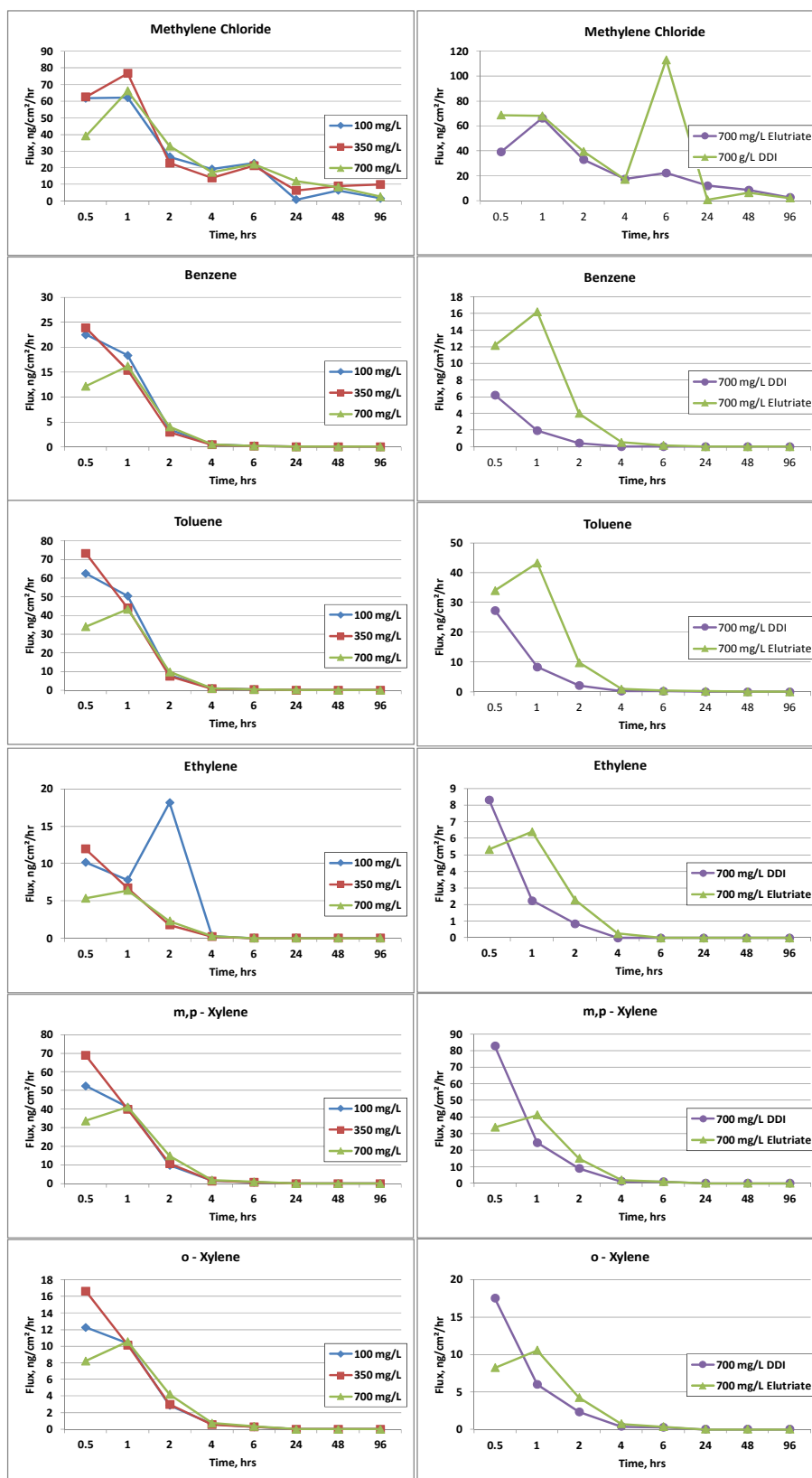


Figure 43. Volatile organic compound flux measurements with time for unamended sediment slurry with 100 mg/L, 350 mg/L, and 700 mg/L TSS in elutriates (left) and 700 mg/L TSS in elutriate and DDI water (right).

time intervals, but fell to less than detectable emissions within 4 to 6 hr. The TSS concentration affected the flux very little. The flux for DDI mixtures was generally less than the elutriate mixtures, suggesting a greater water concentration of volatile organic compounds, hence a greater source, in the elutriate mixtures.

6.3.2 Resuspension chamber volatilization results for unamended sediment

The resuspension chamber tests investigated contaminant flux for dredged material slurry during a quiescent settling period of 10 hr, followed by 144 hr with the oscillation device gently stirring the top one third of the chamber contents. This procedure is designed to simulate resuspension of dredged material solids by wind-driven disturbances of the water column in the storage pond. This mixing, accompanied by desorption of contaminants in the water column, would be expected to provide a source for continued volatilization of contaminants.

Flux estimates for PAHs are shown in Figure 44. The volatile PAH losses decreased during the settling period, and then increased after mixing began. The lower molecular weight (more volatile) compounds exhibited greater flux magnitudes than the higher molecular weight compounds. Except for the naphthalenes, the volatile losses appeared to be continuing beyond the 144-hr observed mixing period.

Volatile organic compound results from the resuspension chamber experiments are shown in Figure 45. The patterns for these contaminants were similar to those seen for the PAHs. During the settling period, the releases declined, but they increased during the mixing period, reaching peak values at 0.5 hr after beginning mixing and declining to near detection by the end of the experiment.

6.3.3 Small flux chamber experimental results for PAC-amended slurry

Small flux chamber experiments were performed for PAC-amended sediment slurries in the same manner as for the unamended slurries discussed in the previous section. After initially preparing a 100-g/L slurry, mixing PAC into the slurry in zero-head-space jars for 15 min., and allowing it to settle 4 hr, the resulting supernatant was loaded into the chamber and the volatilization evaluation began. TSS for the supernatant in the chamber was 860 to 1290 mg/L. Carbon doses of 0.025, 0.050, and 0.10 g/L were mixed

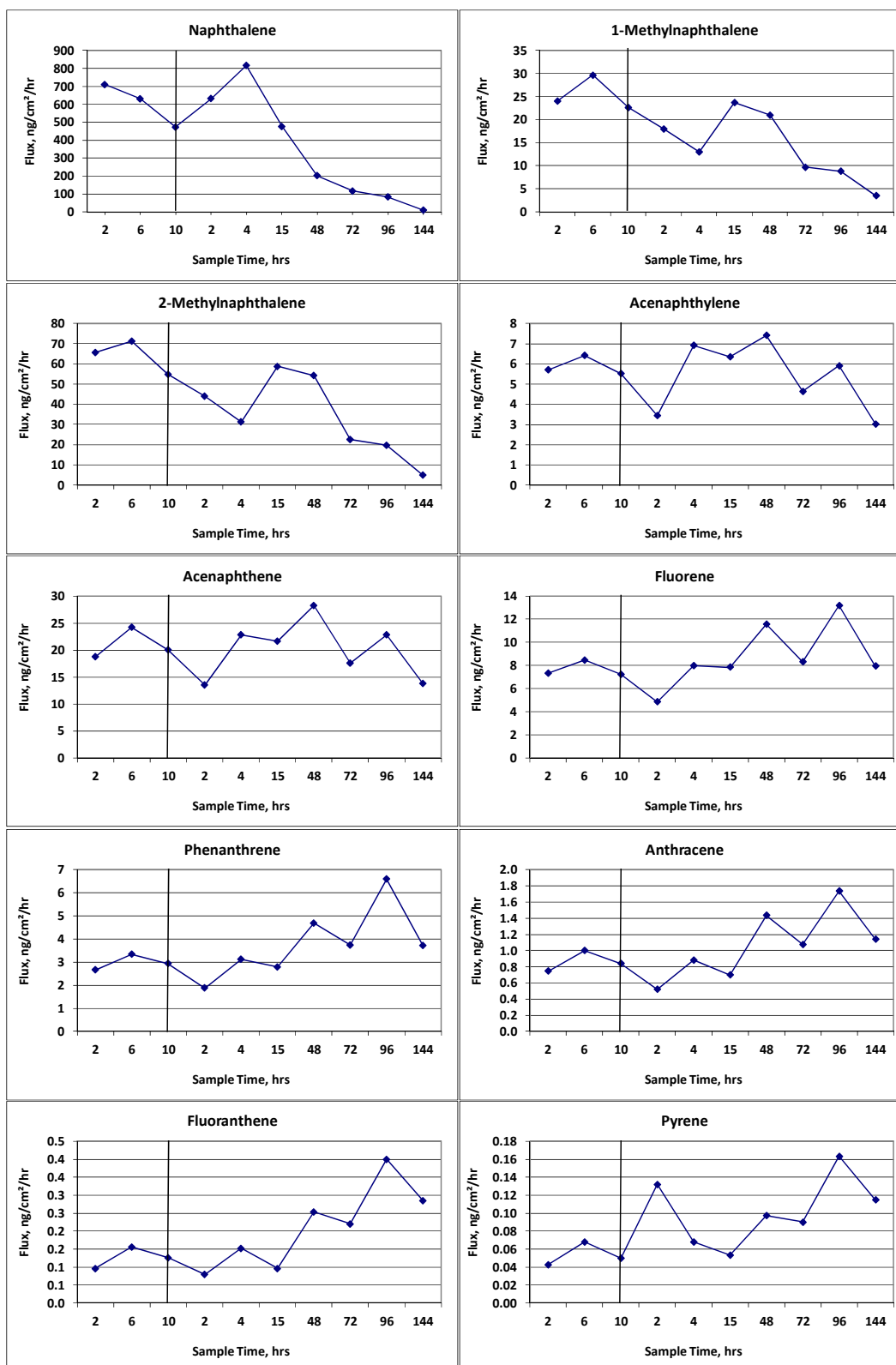


Figure 44. PAH flux observed in resuspension chamber experiments simulating unamended dredged material slurry after initial settling (Note: horizontal axis not to scale).

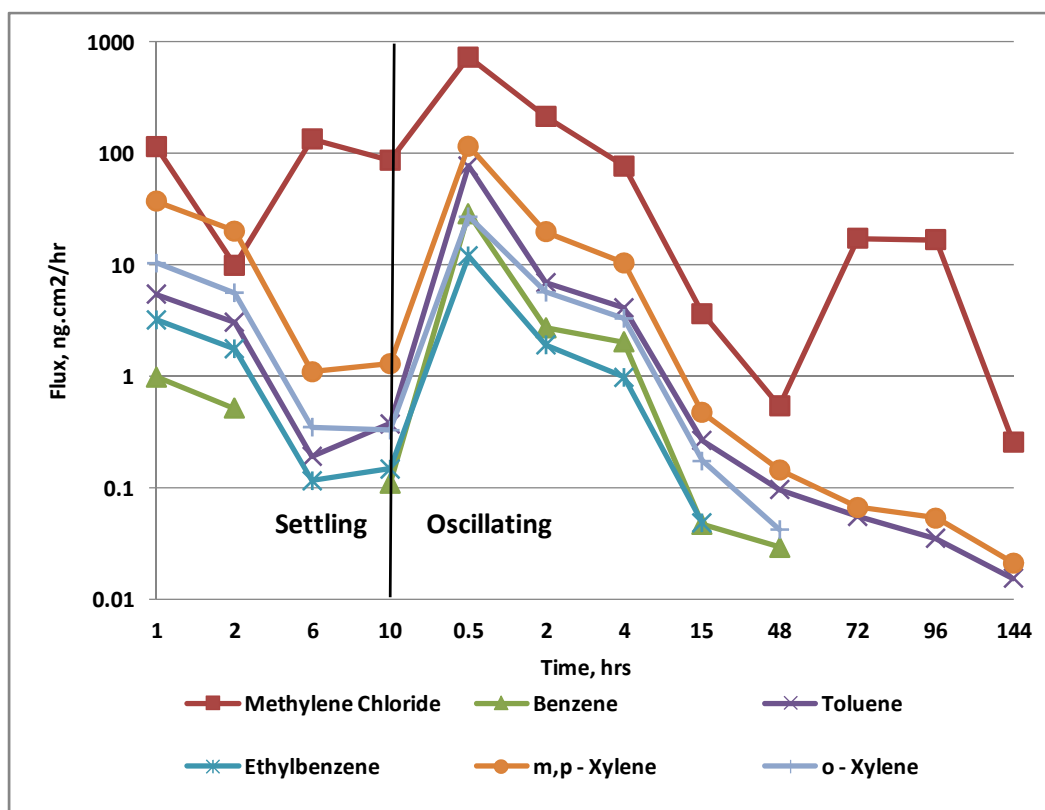


Figure 45. Volatile organic flux observed in resuspension chamber experiments simulating unamended dredged material slurry after initial settling (acetone was below detection) Note: horizontal axis not to scale.

with the 100-g/L slurry, yielding 0.025, 0.050, and 0.10 % PAC to sediment solids. Figure 46 compares the flux for various PAH compounds with time and with carbon dose. The PAH losses generally approach zero after 24 hr with the exception of fluoranthene and pyrene, which trend slightly higher between 24 and 96 hr. Increased PAC concentration showed little improvement in reducing PAH volatile emissions.

Volatile organic compounds data are plotted in Figure 47. Flux for these compounds approaches zero after the first 24 hr, and there is little apparent difference for the three carbon doses, with the exception of the first half hour sample.

PAH emission reductions using PAC to treat the supernatant from the dredged material slurry are illustrated in Figure 48. This graph shows the percent reduction in PAH mass emitted during the course of the experiment from the samples evaluated for PAC-amended slurry compared to the unamended slurry supernatant samples discussed in the previous section. These values were calculated using the following equation:

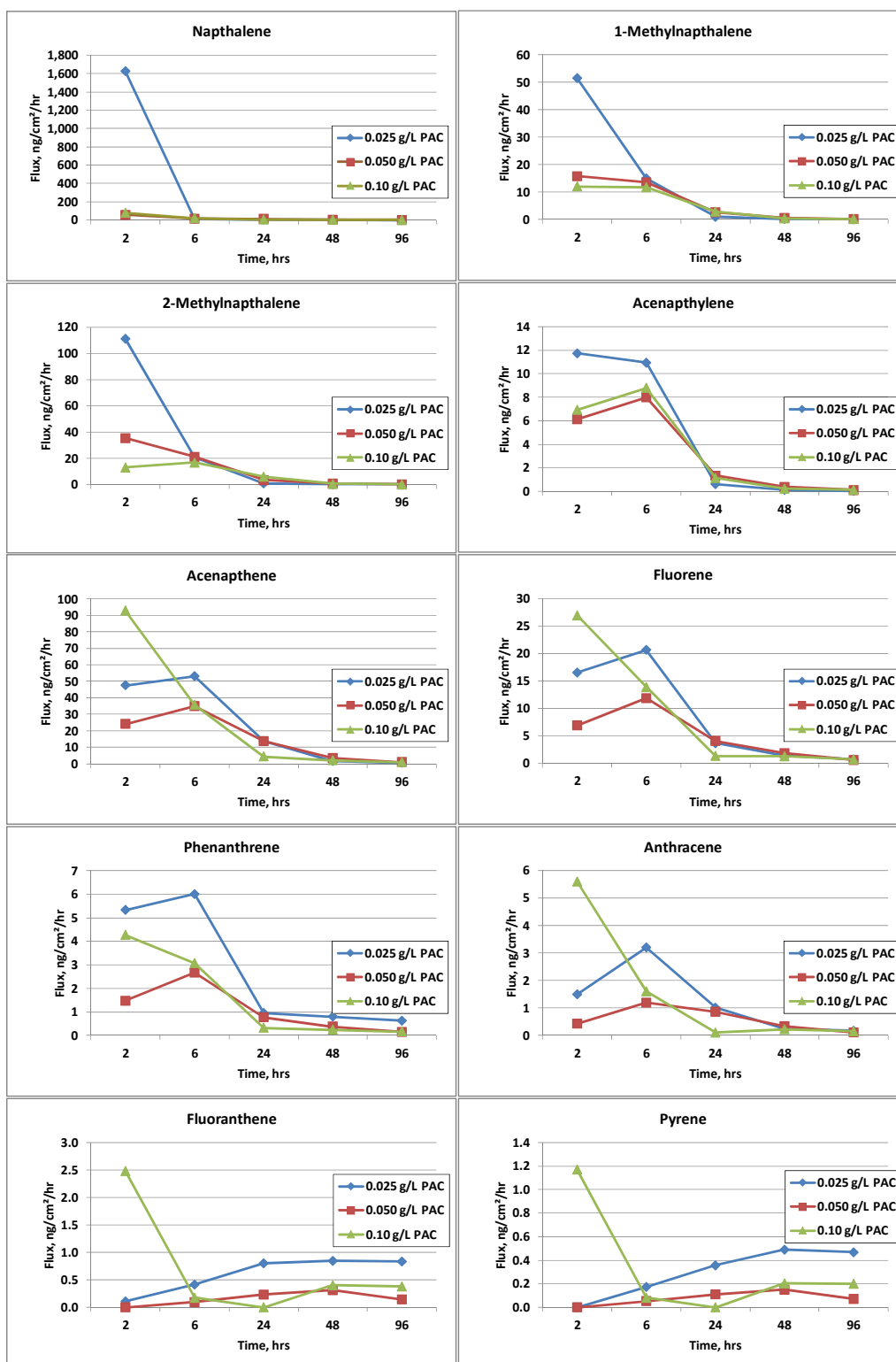


Figure 46. PAH flux for PAC-amended dredged material slurry (Note horizontal axis not to scale).

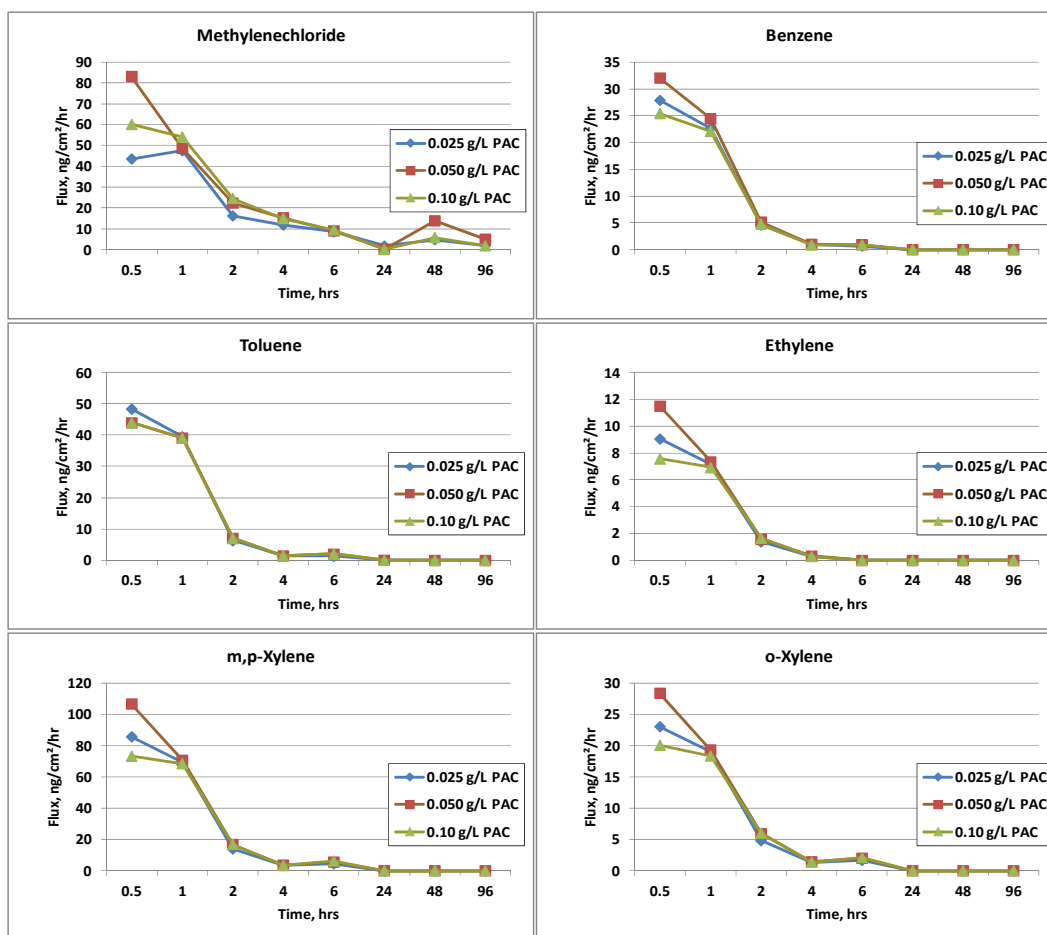


Figure 47. Volatile organic compound flux for PAC-amended dredged material slurry (Note horizontal axis not to scale).

$$\% \text{Reduction} = \frac{\left(\sum_0^t \text{Mass PAH}(\text{untreated}) - \sum_0^t \text{Mass PAH}(\text{carbon treated}) \right)}{\sum_0^t \text{Mass Contaminant}(\text{untreated})} \times 100$$

Where t = run time for the volatilization experiment = 96 hr

PAH reductions (in terms of PAH mass) as high as 94% were observed. Comparison against the 700-mg/L unamended samples demonstrated the greatest effectiveness on a percentage basis because the unamended PAH concentrations were greater. The TSS concentration for the PAC-treated mixtures ranged from 860 to 1290 mg/L; therefore, the 700 mg/L TSS control samples are the best match for comparison. Considerably greater efficiencies were observed between 25 and 50 mg/L PAC for the lower molecular weight compounds. In many cases, going from 50 to 100 mg/L PAC increased effectiveness only marginally. Results for acenaphthene, fluorene, fluoranthene, and pyrene were inconsistent with respect to efficiency, TSS concentration, and carbon dose.

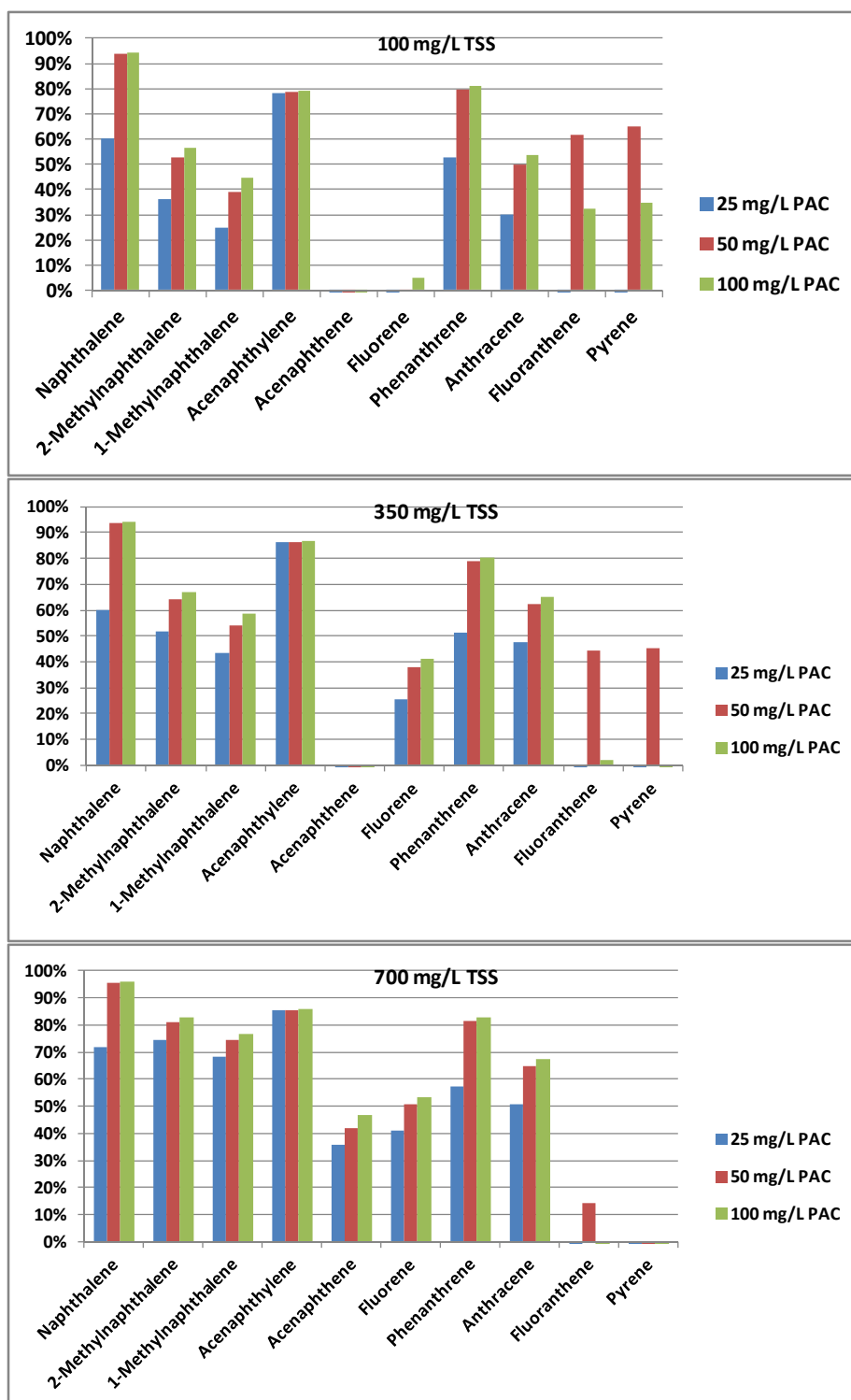


Figure 48. PAH emission reductions for air samples from ponded water with TSS concentrations of 100, 350, and 700 mg/L where dredged material slurry was amended with PAC at doses of 25, 50, and 100 mg/L.

6.3.4 Small chamber results for PAC-amended supernatant (pond water)

As described in Section 6.2.1.3, small-chamber experiments were performed for PAC addition to filtered supernatant that originated from simulated dredged material slurry. Flux measurements with time for PAHs and for VOCs are shown in Figures 49 and 50, respectively. With the exceptions of fluoranthene and pyrene, the flux for each PAH compound decreased with time and approached zero after 96 hr of sampling. Fluoranthene and pyrene peak at 48 hr and then decrease at 96 hr. The 0.5 and 1.0 mg/L PAC doses appear to have reduced the PAH flux compared to 0.1 mg/L PAC, thus indicating that the fluxes for the VOCs decline to below detection within 4 to 24 hr. Effects of carbon dose are inconsistent.

The removal effectiveness for PAC treatment of dissolved PAHs is illustrated in Figure 51 when compared to unamended flux at 100, 350, and 700 mg/L TSS. Greater efficiencies are shown for the 700-mg/L TSS chart because of greater PAH values for the untreated water. This chart shows efficiencies ranging from 20 to 96%. The higher molecular weight PAH generally exhibited lower efficiencies. Higher carbon doses generally were more efficient, but this was not true for all compounds--for example, naphthalene and methylnaphthalene.

6.3.5 Comparison of PAC treatment of slurry compared to ponded water

An important factor in implementing carbon adsorption to reduce volatile losses from a dredging project is determining the optimum point of injection for the PAC. The small flux chamber results presented in Sections 6.3.3 and 6.3.4 provide data to address this question. Figure 52 compares PAH removal efficiencies for PAC addition to slurry at PAC doses of 25 and 100 mg/L to PAC addition to ponded water at PAC doses of 0.1 and 1.0 mg/L. The basis for emissions without PAC was extracted from data for the 700-mg/L TSS in elutriate samples. For the three naphthalene compounds and for acenaphthene, the ponded water treatment was more effective even though the carbon mass is two to three orders of magnitude lower than for the slurry treatment. For acenaphthylene and anthracene, slurry treatment provided greater removal efficiencies for all doses. Removal efficiencies for fluorene and phenanthrene were better for 1.0 mg/L water treatment than for 25 mg/L slurry treatment. Fluoranthene and pyrene samples treated with carbon lost more PAHs than the untreated samples, which resulted in negative removal efficiencies.

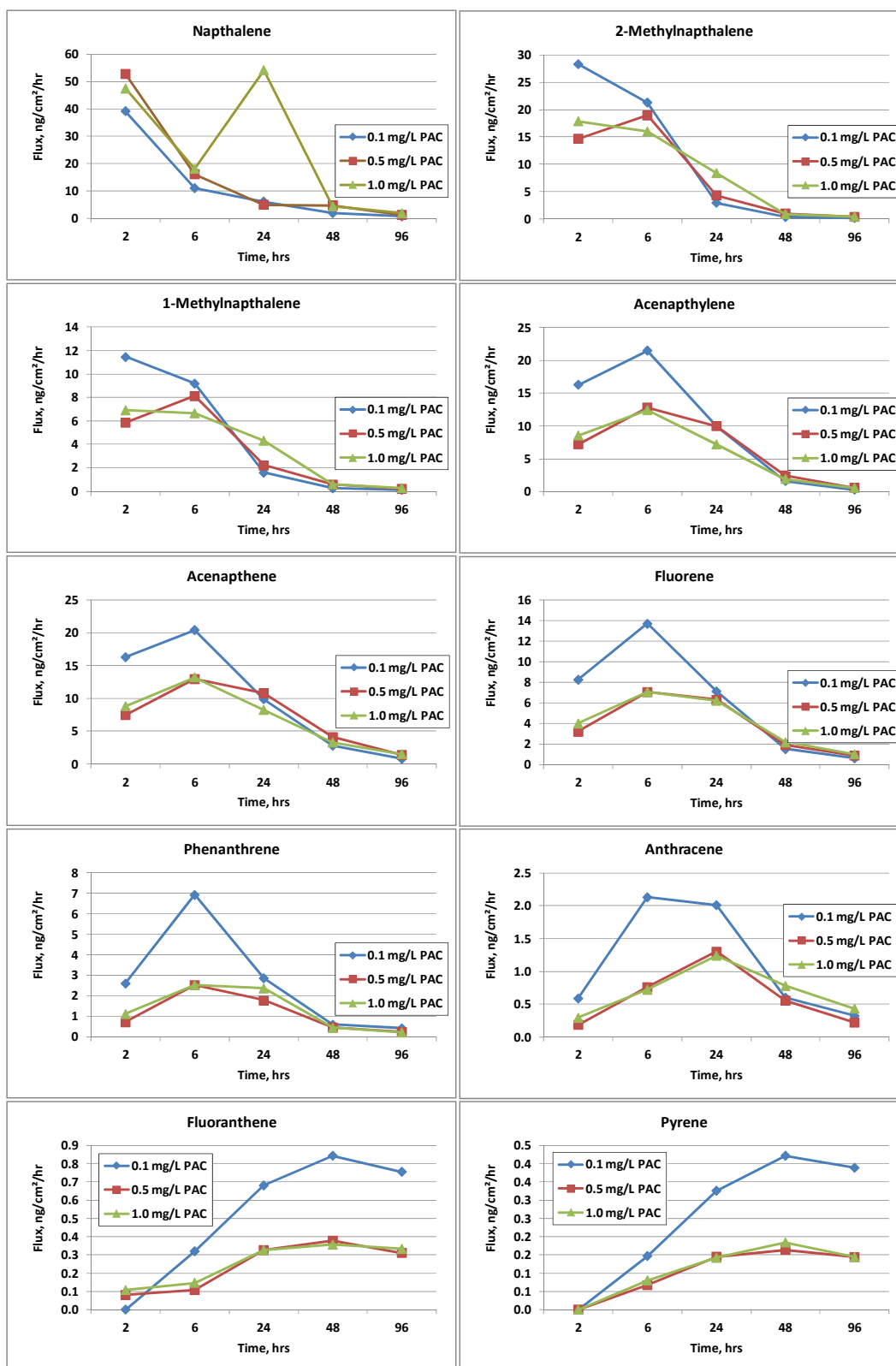


Figure 49. PAH flux for ponded water (filtered dredged material slurry) amended with PAC
 Note: horizontal axis not to scale.

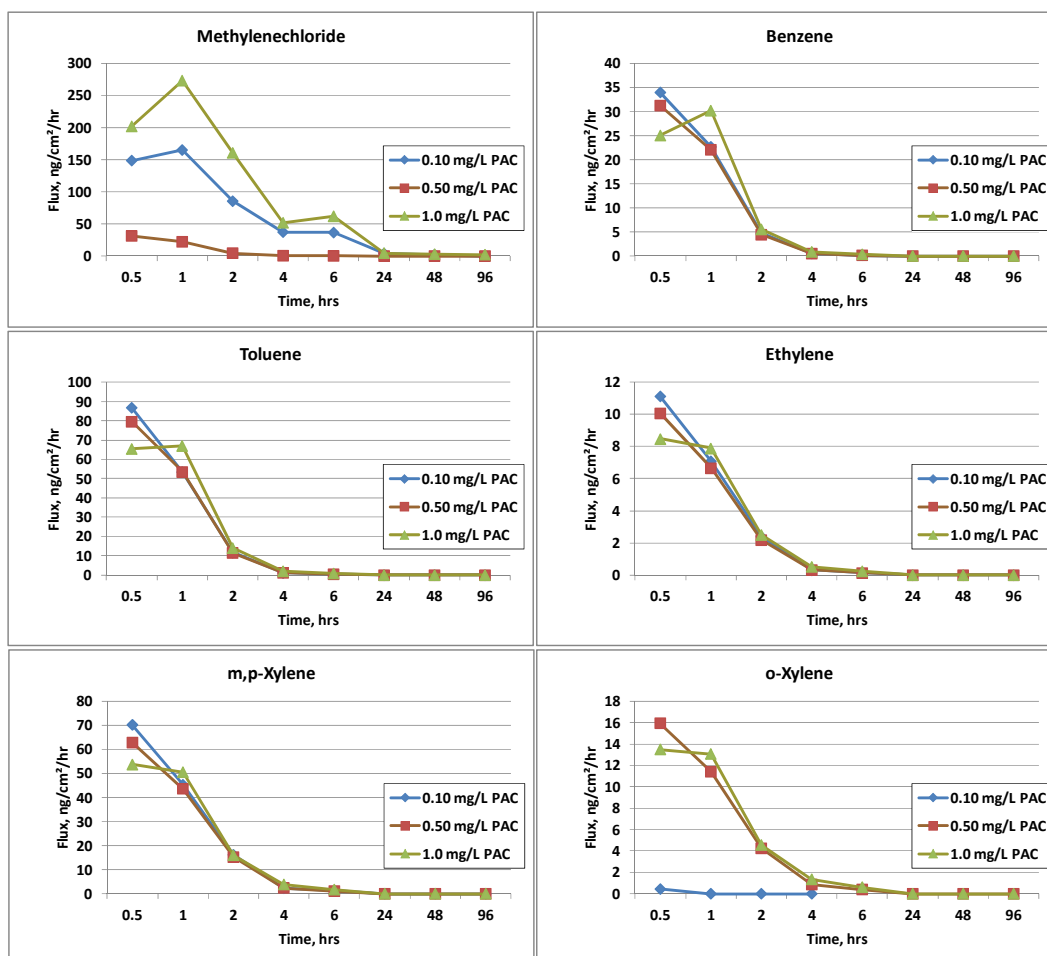


Figure 50. Volatile organic compound flux for ponded water (filtered dredged material slurry) amended with PAC Note: horizontal axis not to scale.

6.3.6 Small chamber results for PAC- and GAC-amended exposed sediment

The next set of experiments investigated PAH flux from exposed sediment that was moist and near the original sediment solids content (490-560 g/L total solids). PAH flux estimates for the unamended sediment are illustrated in Figure 53. Losses for pyrene and anthracene held steady for the entire 168 hr of sampling, whereas other compounds generally decreased during the sampling period. Note that the flux magnitude for various PAH compounds ranges several orders of magnitude.

Figure 54 compares the unamended exposed sediment flux to the same sediment amended with 5 mg PAC per gram sediment solids and with 5, 10, and 50 mg GAC per gram sediment solids. The PAC was usually more effective than the GAC, even when the GAC was at higher carbon-to-solid ratios. The flux for each of the 10 mg/g GAC mixtures was consistently

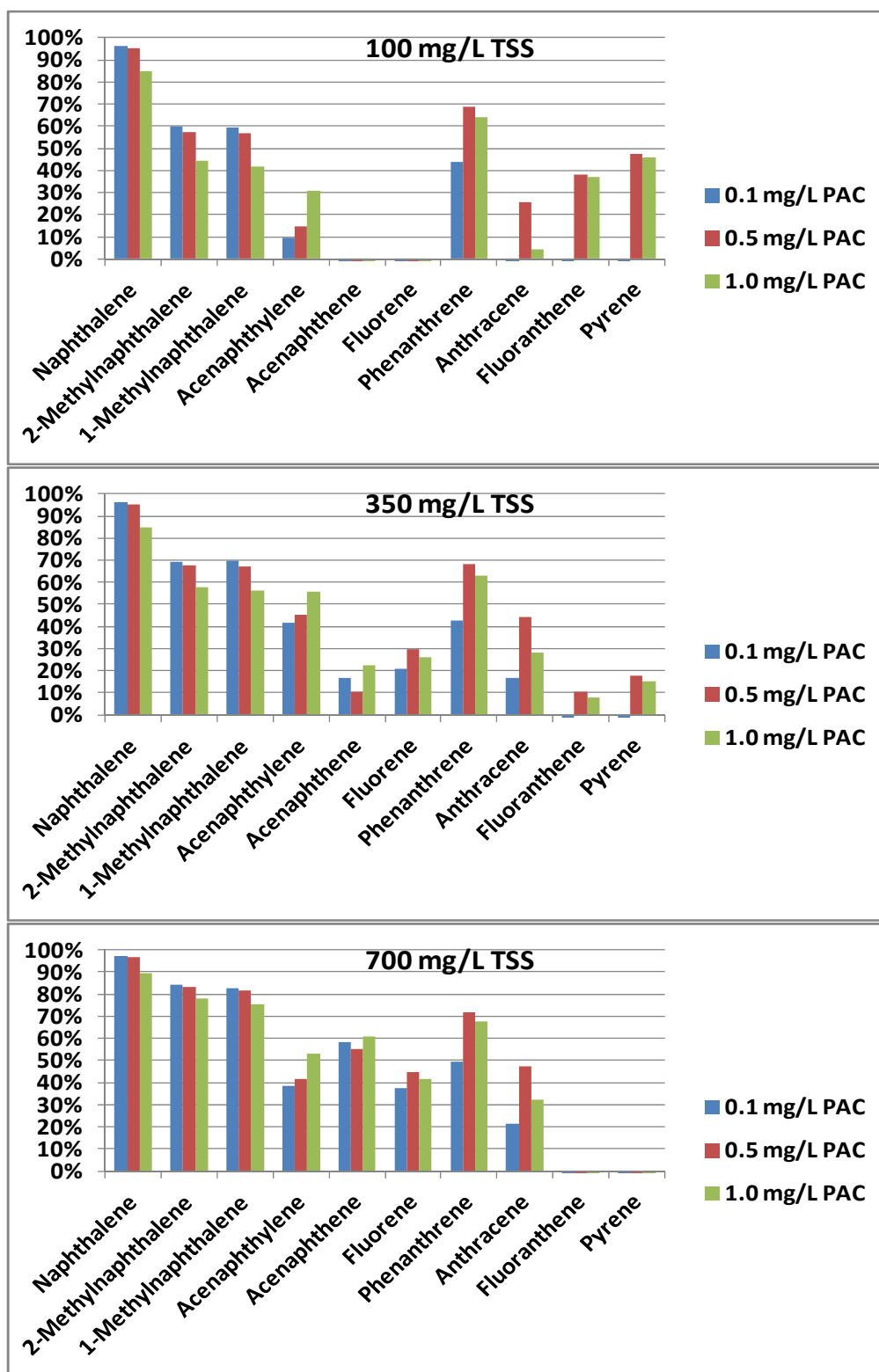


Figure 51. PAH removal with PAC added to laboratory-simulated ponded water (filtered) compared to losses from unamended ponded water at 3 TSS concentrations.

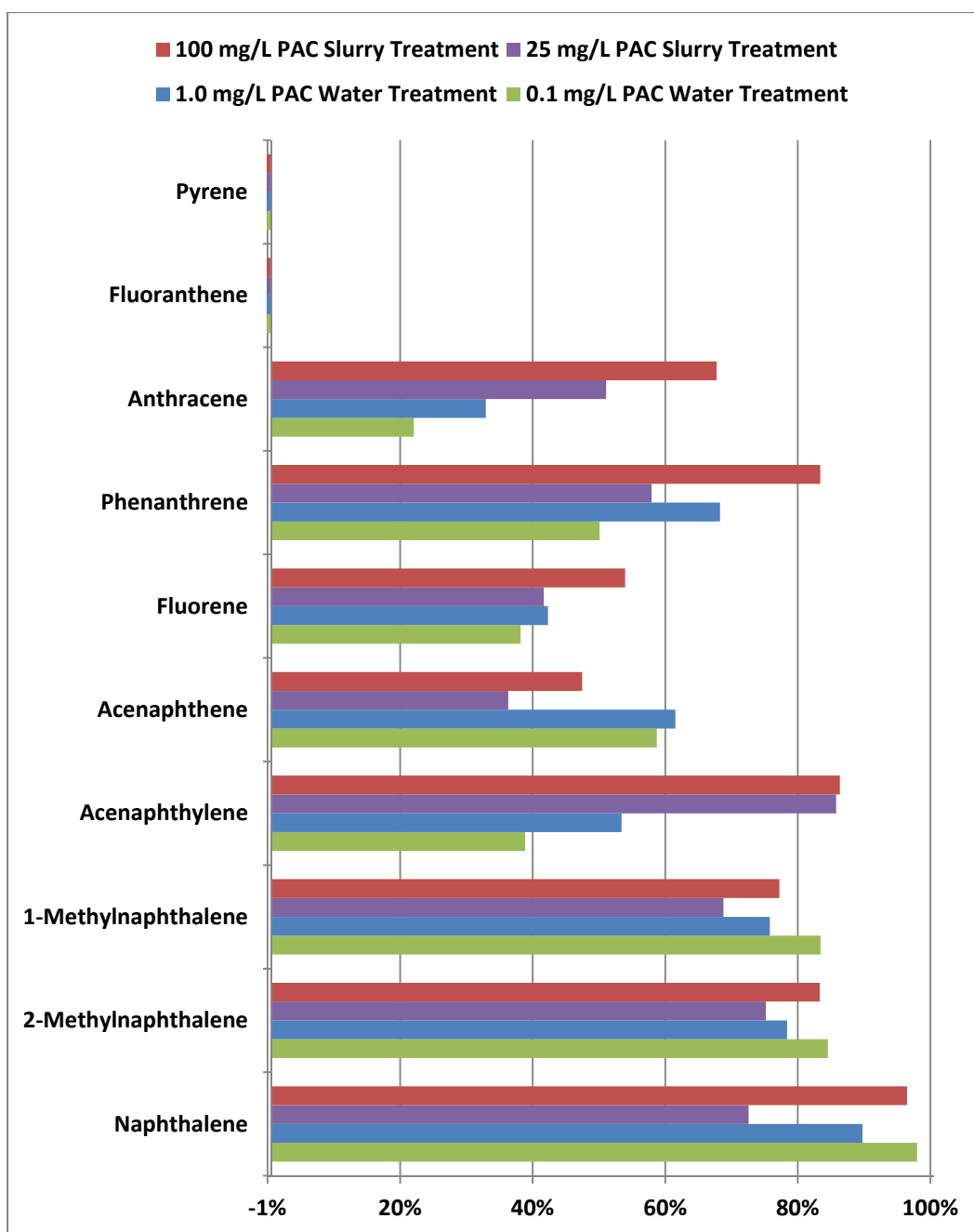


Figure 52. Comparison of removal efficiencies for PAC amended dredged material slurry to PAC amended ponded water.

greater than the other test materials. This may be explained from much greater PAH concentrations in the sediment compared to the other three sediments. As discussed earlier, the original sediment containers were not mixed or homogenized to avoid volatile losses that would occur with mixing.

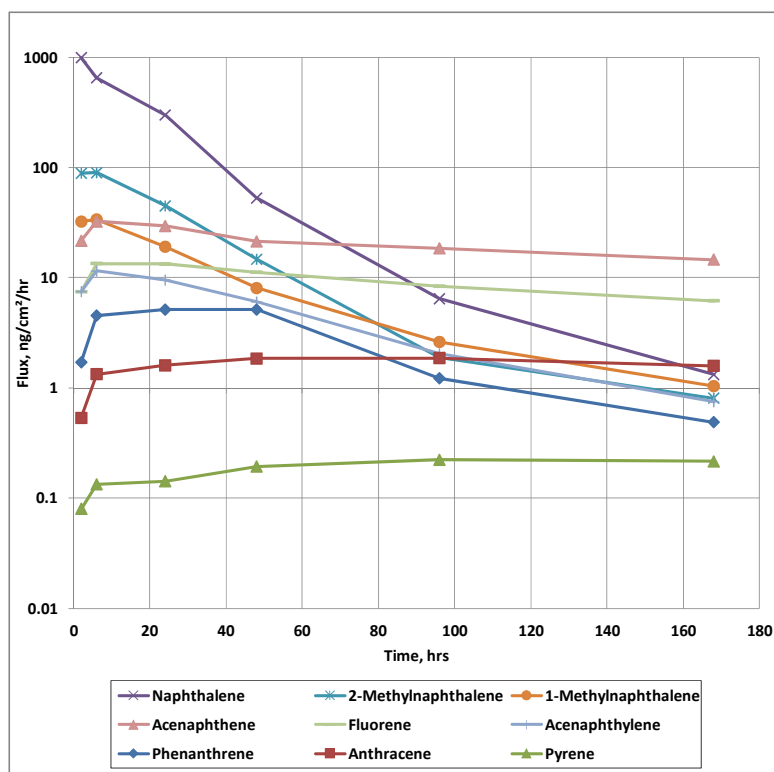


Figure 53. PAH losses from unamended exposed sediment.

Figure 55 shows the removal effectiveness for specimens amended with 5 mg PAC per gram sediment and with 5 and 50 mg GAC per gram sediment. This confirms the observation that the PAC was more effective than the GAC in removing PAHs where the carbon doses were the same magnitude. Increasing the GAC concentration by an order of magnitude to 50 mg/g improved efficiency, but the improvement was not proportional to the increased carbon required. Selecting a formulation for field application would require a cost comparison between a lower dose of PAC, which costs more per unit mass, to a higher dose of GAC, which has a lower unit cost and is easier to handle and mix with the sediment.

6.3.7 Wind tunnel experimental results

IHC sediment amended with 10 mg/g PAC (1%) was tested in the ERDC wind tunnel to evaluate particulate losses of PAHs adsorbed to sediment or carbon particles. The experiment was conducted over the course of several months as the sediment dried. Wind speeds of 2.5, 5, 7, and 10 mph were compared to background conditions with no wind in the tunnel and with 10 mph movement into the tunnel. Results of the particulate analysis are shown in Figure 56. Particulate losses ranged from 0.08 g/d at 2.5 mph to 0.14 g/d at 10 mph. The intent was to analyze these particles for PAHs in

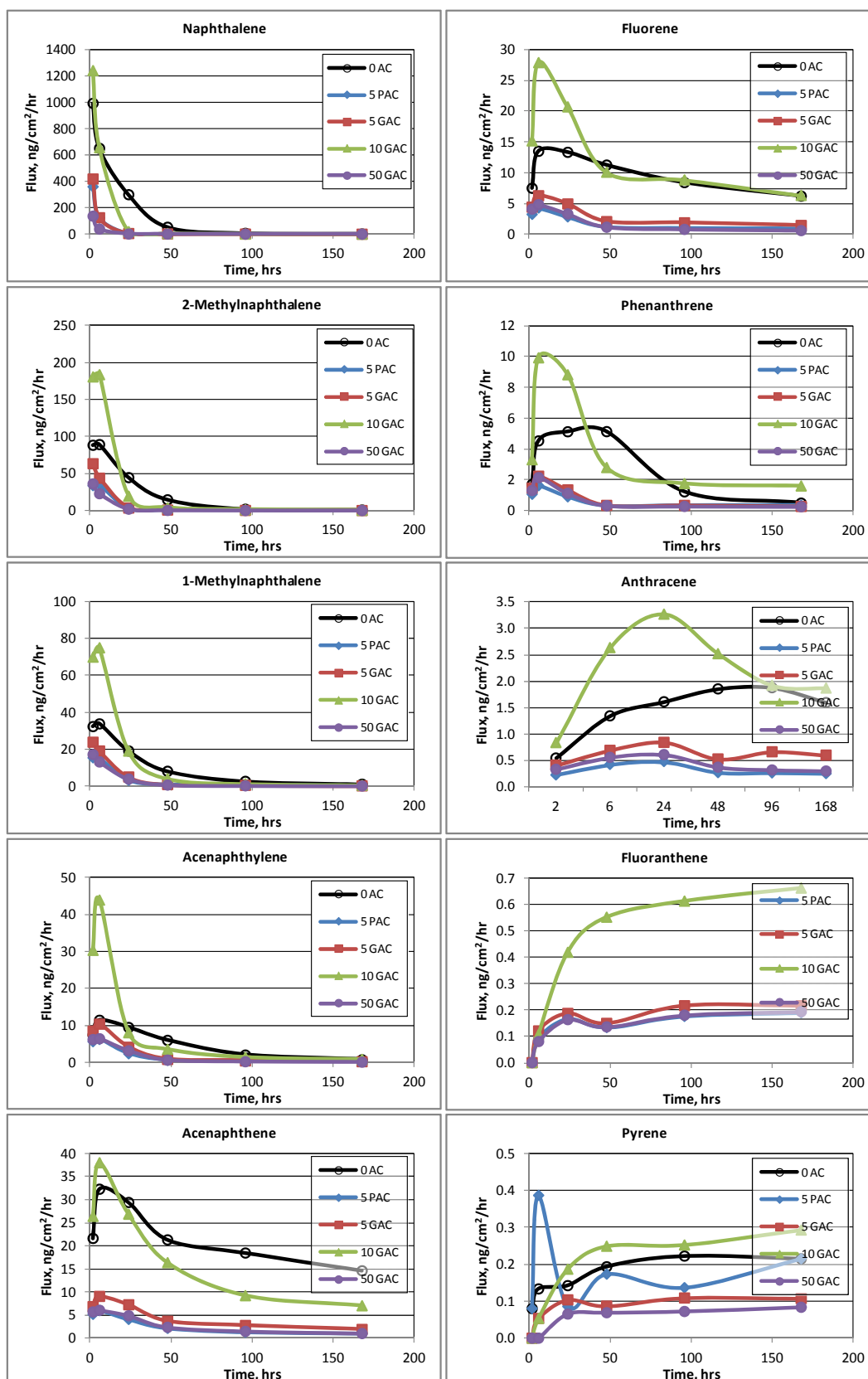


Figure 54. PAH flux for exposed sediment comparing unamended to PAC- and GAC-amended sediment (data of 0 AC not available for fluoranthene).

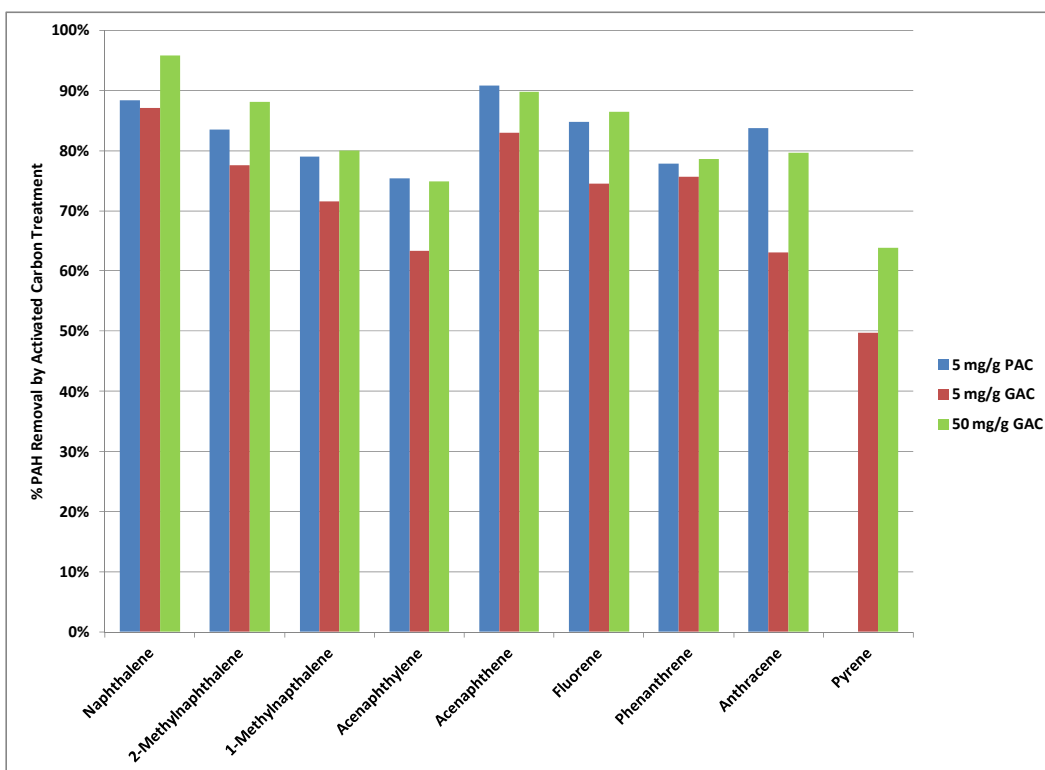


Figure 55. Percent PAH removal for PAC/GAC amended exposed sediment compared to unamended exposed sediment.

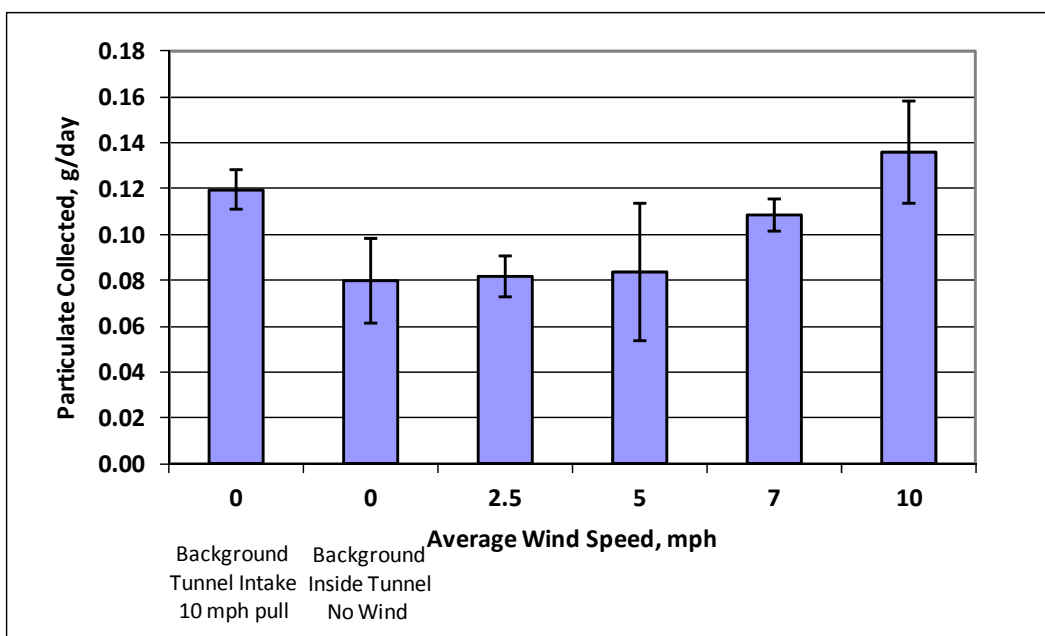


Figure 56. Particulate losses from exposed dredged material at various wind speeds during wind tunnel experiments.

order to estimate PAH losses associated with particulates. However, the small quantities of dust collected were insufficient for detection of PAHs by analysis of the particles.

In an effort to evaluate the potential for particulate losses, unamended sediment, sediment amended with PAC, and surface dust from the wind tunnel were separated into two density fractions by using a heavy media technique described earlier. Results of the analyses of the sinks (heavier particles) and floats (lighter particles) for each of the three samples by this procedure are shown in Figure 57. The observed results are contrary to what was expected. The lighter particles generally contained lower PAH concentrations compared to the heavier particles. Lighter particles should have contained the organic matter and PAC, which usually is enriched with organic contaminants. The dense media separation process may not have been as efficient as expected and some of the lighter material may have reported to the top of the sink layer, but this is speculative. From the viewpoint of particulate losses due to wind, lower concentrations in the lighter particles would be more beneficial.

The surface dust samples exhibited lower PAH concentrations, perhaps due to a depletion of the PAHs from the sediment surface during the wind tunnel tests. The unamended particles appear to exhibit greater PAH concentrations than the PAC-treated particles, but this may be due to differences in bulk PAH concentration for the samples evaluated.

The lower molecular weight and more volatile PAHs showed lower particulate concentrations than the larger compounds, possibly due to volatile losses during sample preparation or storage.

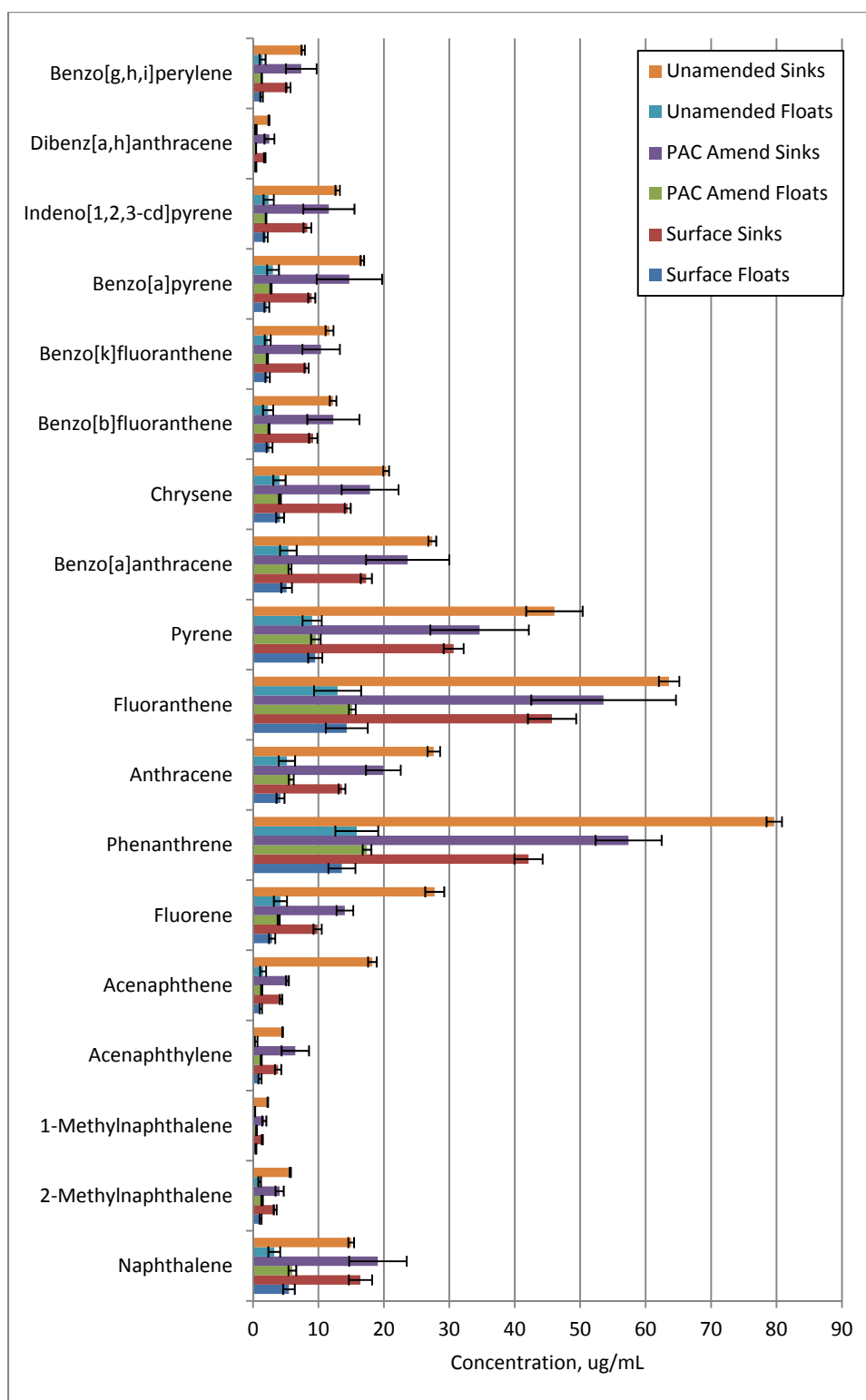


Figure 57. Characterization of PAH concentration in particle size fractions for wind tunnel sediment.

7 Conclusions

Chemical analyses showed that the IHC Turning Basin sediment collected by CELRC was sufficiently contaminated for investigation of volatile emission processes and the potential for activated carbon to control volatile emissions. Chemical characterization tests also showed that IHC Turning Basin sediment is similar in chemical contamination to the IHC sediment collected in 1987 for evaluation of disposal alternatives.

Based on settling tests, a regenerated carbon was selected for further study. Regenerated carbon is about one-half the cost (exclusive of transportation costs) of virgin activated carbon. Adsorption isotherms were obtained for PAC and GAC. PAC isotherm data were used to estimate carbon dose for volatilization studies, and the GAC isotherm data may be used to evaluate CDF effluent treatment by carbon adsorption. The adsorption isotherm data showed that carbon adsorption was very effective for the removal of three- and higher-ring PAHs from water, and therefore should be very effective for controlling volatile emissions of these PAHs. The adsorption data suggested that two-ring PAHs can be reduced and even eliminated from CDF effluent if the carbon dose is sufficiently high. Adsorption of VOCs by activated carbon was poor in some cases, e.g., acetone.

Column settling tests showed that PAC addition to dredged material slurries either enhanced settling or had no effect, depending on the starting slurry density.

Carbon treatment of dredged material slurry, dredged material ponded water, and exposed dredged material solids effectively reduced volatilization of PAHs. The effectiveness varied from compound to compound, but generally greater removal efficiencies were observed for the lower molecular weight (<200 g/g mole) PAHs. Emissions for PAHs with four or more benzene rings were below detection for both treated and untreated samples. Carbon treatment of slurry and pond water had little effect in reducing VOC emissions.

Treatment of ponded water at lower carbon doses competed very well with treatment of slurry and carbon doses two orders of magnitude higher. PAC doses of 0.05% and 0.1% g PAC/g slurry solids (50 mg/L to 100 mg/L

slurry) in the influent slurry reduced emissions by 36% to 96% for naphthalene, methylnaphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene in dredged material slurry. No improvement was observed for fluoranthene, pyrene, and higher molecular weight PAHs.

Low molecular weight PAH emissions from ponded water (supernatant) were reduced by 22% to 98% at PAC dosages of 0.1 mg/L, 0.5 mg/L, and 1.0 mg/L.

PAH flux was also evaluated for exposed (dewatered, but moist) dredged material. Emission differences as high as 96% for naphthalene were observed for 50 mg GAC per g solids (5%). Volatile reductions were also observed in most cases for other low molecular weight PAHs. Comparison of PAC and GAC in equal dosages of 0.5% demonstrated approximately 12% greater reduction for the PAC compared to the GAC. Increasing GAC dosage from 0.5% to 5% improved reductions by an average of 15%.

Mixing of simulated pond water in the large flux chamber renewed volatile compound flux after the flux generally declined during a preliminary settling period. This suggests that mixing at the surface and perhaps resuspension of dredged material particles renews the source for volatilization losses.

Particulates measured in exhaust from a wind tunnel confirmed a dependence on wind speed. Attempts to quantify PAH losses with the particulate losses were unsuccessful. Analysis of sediment particles fractionated by density in unamended and PAC-amended IHC samples showed that the lighter PAC fractions contained less PAH than the heavier sediment particles.

The inconsistency observed for some of the laboratory data is probably due to the heterogeneity of the sediment in the canal. Because this study focused on volatile chemicals, compositing and homogenizing laboratory samples were intentionally avoided to minimize volatile losses during sample preparation.

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Appendix A: Memorandum for Record - Sediment Sampling in Indiana Harbor

CELRC-TS-HE June 15, 2005

MEMORANDUM FOR RECORD

RE: Sediment sampling in Indiana Harbor – In Support of Carbon Adsorption Research

1. On June 7th and 8th 2005, the U.S. Environmental Protection Agency (USEPA) Research Vessel (R/V) *Mudpuppy* was deployed for sediment sampling in Indiana Harbor, which is located north of East Chicago, IN. The purpose of this expedition was to collect approximately 225 gallons of Indiana Harbor sediment for use in carbon adsorption experiments, by the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES).
2. Due to the nature of this research, one of the primary goals of the sampling campaign was to obtain material with elevated levels of contaminants. Consequently, the area identified for sampling was located in the southern corner of the main turning basin, adjacent to the Indiana Harbor entrance (Figure 1 of main body of report). This area has been historically identified as having the potential to contain concentrations of volatile organic compounds (VOCs) at levels higher than surrounding portions of the Indiana Harbor and Canal vicinity.
3. Another objective of the sampling effort was to obtain a sediment core representative of the full final dredge depth in the harbor, which is identified to be a depth of 28 feet below LWD (IGLD85). A recent survey identified the sediment surface in the sampling area ranging in depth from approximately 8-14 feet below LWD. For this reason, a Vibracore sampling apparatus, equipped with a 15-foot length core tube, was utilized to collect the sediment samples. Briefly, a Vibracore sampler produces a high frequency, low amplitude vibration that is transferred from the Vibracore head down through the core tube. The vibrational energy liquefies sediments, enabling the core barrel to penetrate into the sediment column. A one-way cap is attached to the bottom end of the core tube, which holds the sediment inside the barrel when it is withdrawn from the sediments.
4. Once each core tube is driven into the sediments, it is hoisted onto the deck of the R/V *Mudpuppy*, cut into three sections – for ease of handling – and emptied into 5-gallon buckets. If full, each core tube was able to fill approximately 1.5 buckets worth of sediment. The buckets were filled to minimize headspace, capped with a rubber-sealed lid, and hammered shut in order to minimize volatile losses. No specific measures were taken to label the buckets with location or time data, since all buckets are expected to be homogenized upon receipt by WES.
5. During the sampling days, the buckets were temporarily stored either on the boat, or on a dock adjacent to the sampling area, and the temperature of the buckets was not controlled. Meteorological conditions during the two days of sampling were warm and sunny, with a high temperature ranging from 85-90 °F.

At the conclusion of each sampling day, the buckets were transported via cargo van to a cold storage warehouse, where they were kept at a temperature of 35-40 °F. The contact information for the storage warehouse is as follows:

Berkshire Refrigerated Warehousing
C/O Midway Distribution
4550 S. Packers Ave
Chicago IL, 60609
Contact: John Kaznak – (773) 254-2424
Midway Distribution – (800) 886-9094

The buckets were scheduled to leave the Chicago vicinity on Thursday, June 9th, and were transported to WES via a temperature-controlled truck.

6. Table A1 summarizes actual sampling conditions, and notes any variances from the above-described methods.

Table A1: Sampling statistics

Date	Time	Location	Measured Water Depth	No. of Buckets	Notes
June 7, 2005	Morning (9:30-12:30)	41°39'54.00" - 87°26'16.20"	11 ft	9	First 5 buckets, tube approx 2/3 full (10ft) – re-drove to fill core tube. Repositioned.
June 7, 2005	Afternoon (14:00-16:30)	41°39'53.94" - 87°26'16.86"	13.5 ft	12	Deeper water depth allowed full 15 ft cores; characterizing 28' depth.
June 8, 2005	Morning (8:30-11:00)	41°39'53.94" - 87°26'16.32"	14 ft	19	Full tubes all morning
June 8, 2005	Afternoon (11:30-12:30)	41°39'54.00" - 87°26'16.56"	13.5 ft	5	

7. Any comments or questions in regard to this memorandum may be directed to the undersigned at (312) 846-5522.

/s/

DAVID M. WETHINGTON
Environmental Engineering

Section

Appendix B: Batch Activated Carbon Adsorption Data

Table B1. PAC batch PAH concentrations (µg/L) and sediment concentration (mg/kg)

PAC dose (g/L)	Replicate	PAH							
		2MeNAPH	NAPHTH	ACENAY	ACENAP	FLUORE	PHENAN	ANTRAC	FLANTHE
0.01	1	13.40	848.00	33.10	22.70	16.40	10.60	1.48	0.99
	2	10.80	515.00	23.20	15.80	11.40	7.35	1.92	0.75
	3	24.00	819.00	26.90	18.70	12.40	7.61	1.08	0.85
0.05	1	2.29	242.00	3.15	1.62	0.75	0.48	0.12	0.50
	2	2.40	251.00	3.01	1.51	0.68	0.33	0.09	0.23
	3	2.17	213.00	3.13	1.59	0.74	0.52	0.16	0.41
0.10	1	0.30	30.60	0.37	0.22	0.11	0.09	<0.01	0.05
	2	0.42	52.20	0.50	0.30	0.14	0.11	<0.01	0.07
	3	0.44	50.20	0.51	0.30	0.15	0.10	<0.01	0.06
0.50	1	<0.01	0.55	<0.01	<0.01	<0.01	0.05	<0.01	0.06
	2	<0.01	0.76	<0.01	<0.01	<0.01	0.05	<0.01	0.06
	3	<0.01	0.83	<0.01	<0.01	<0.01	0.04	<0.01	0.03
1.0	1	0.13	2.33	0.11	0.09	0.09	0.14	0.03	0.06
	2	<0.01	0.46	<0.01	<0.01	<0.01	0.08	<0.01	0.17
	3	<0.01	0.31	<0.01	<0.01	<0.01	0.05	<0.01	0.06
Elutriate		10.8	562	26.9	23.8	26.7	39.9	15	12.8
Sediment		194	975	103	240	271	810	275	595

Note: See Table 2 of main text for PAH CAS numbers and long and short names.

Sediment used to prepare elutriate.

(continued)

Table B1. (concluded)

PAC Dose (g/L)	Rep	PAH								
		PYRENE	CHRYSE	BAPYRE	BAANTHR	BBFLANT	BKFLANT	I123PYR	DBAHANT	B-GHI-PY
0.01	1	0.55	0.08	0.07	0.15	0.07	0.06	0.13	0.09	0.08
	2	0.55	0.05	0.05	0.14	0.05	0.04	0.09	0.09	0.06
	3	0.50	0.07	0.05	0.14	0.05	0.03	0.07	0.07	0.04
0.05	1	0.35	0.07	0.05	0.14	0.06	0.03	0.07	0.07	0.04
	2	0.16	0.04	0.03	0.08	0.03	0.03	0.04	0.04	0.03
	3	0.26	0.04	0.03	0.08	0.04	0.03	0.04	0.03	<0.01
0.10	1	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
	2	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	3	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
0.50	1	0.04	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
	2	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
1.0	1	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	2	0.12	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01
	3	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
E		7.7	0.86	0.39	1.26	0.56	0.18	0.13	.03J	0.11
S		357	219	211	248	176	158	118	19.7	97.7

E: Elutriate

Rep: Replicate

S: Sediment used to prepare elutriate

Note: See Table 2 of main text for PAH CAS numbers and long and short names.

Table B2. GAC batch PAH concentrations ($\mu\text{g/L}$) and sediment concentration (mg/kg).

GAC dose (g/L)	Rep	PAH							
		2MeNAPH	NAPHTH	ACENAY	ACENAP	FLUORE	PHENAN	ANTRAC	FLANTHE
0.01	1	7.88	482	34.9	23.8	25.9	31.1	6.17	4.2
	2	7.95	647	34.1	23.6	23.2	22.4	3.73	2.42
	3	6.44	430	31.3	20.6	21.1	22.5	3.49	2.55
0.05	1	8.23	416	23.1	18.6	18.1	21.2	5.38	3.98
	2	9.09	382	23.9	20.4	19.2	21	5.1	3.68
	3	8.27	395	23.3	18.8	19	22.7	5.04	3.39
0.10	1	8.93	367	22.2	17.8	19.5	21.8	4.87	3.18
	2	8.81	572	30.6	22.7	20.6	19.3	3.64	2.67
	3	8.04	402	23.2	18.3	17.9	18	3.53	2.4
0.50	1	3.81	106	5.22	4.65	3.28	4.05	0.85	1.07
	2	4.16	112	5.34	4.73	3.69	4.54	1.5	1.34
	3	2.53	58.1	3.94	3.56	2.72	3.32	1.03	0.96
1.0	1	0.68	16.3	1.1	1.2	0.85	1.21	0.35	0.37
	2	0.72	17.6	1.03	1.11	0.79	1.17	0.35	0.46
	3	0.43	10.9	0.7	0.75	0.52	0.69	0.23	0.26
Elutriate		10.8	562	26.9	23.8	26.7	39.9	15	12.8
Sediment		194	975	103	240	271	810	275	595

Note: See Table 2 of main text for PAH CAS numbers and long and short names.

Sediment used to prepare elutriate.

(continued)

Table B2. (concluded).

GAC dose (g/L)	Rep	PAH								
		PYRENE	CHRYSE	BAPYRE	BAANTHR	BBFLANT	BKFLANT	I123PYR	DBAHANT	B-GHI-PY
0.01	1	2.04	0.12	0.05	0.20	0.06	0.03	0.04	<0.01	0.03
	2	1.26	0.05	0.00	0.10	0.03	<0.01	<0.01	<0.01	<0.01
	3	1.38	0.08	0.03	0.15	0.04	<0.01	<0.01	<0.01	<0.01
0.05	1	2.31	0.18	0.08	0.34	0.12	0.05	0.05	<0.01	<0.01
	2	1.92	0.15	0.08	0.29	0.09	<0.01	0.05	<0.01	<0.01
	3	1.86	0.13	0.06	0.23	0.07	<0.01	0.00	<0.01	<0.01
0.10	1	1.93	0.14	0.07	0.24	0.09	0.03	0.03	<0.01	0.03
	2	1.41	0.10	0.04	0.17	0.05	<0.01	<0.01	<0.01	<0.01
	3	1.36	0.08	0.03	0.15	0.05	<0.01	<0.01	<0.01	<0.01
0.50	1	0.66	0.07	0.03	0.16	0.04	<0.01	<0.01	<0.01	<0.01
	2	0.79	0.08	0.04	0.13	0.06	<0.01	<0.01	<0.01	<0.01
	3	0.61	0.05	0.04	0.07	0.05	<0.01	<0.01	<0.01	<0.01
1.0	1	0.24	<0.01	<0.01	0.04	0.00	<0.01	<0.01	<0.01	<0.01
	2	0.28	0.06	0.05	0.10	0.05	<0.01	<0.01	<0.01	<0.01
	3	0.17	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
E		7.7	0.86	0.39	1.26	0.56	0.18	0.13	.03J	0.11
S		357	219	211	248	176	158	118	19.7	97.7

E: Elutriate

Rep: Replicate

S: Sediment used to prepare elutriate

Note: See table2 of main text for PAH CAS numbers and long and short names.

Table B3. PAC batch VOC concentrations (µg/L) and sediment concentration (µg/kg).

PAC dose (g/L)	Rep	VOC					
		Acetone	CH ₂ Cl ₂	Benzene	Toluene	Total Xylenes	Ethylbenzene
0.01	1	49.4	<0.50	15	8.5	19.8	1
	2	49.7	<0.50	14.4	8.3	19.5	1.1
	3	54.7	<0.50	14.6	8.2	19.8	1.1
0.05	1	70.4	<0.50	21.2	9.1	12.5	0.9
	2	71.9	<0.50	21.4	9.2	12.4	0.8
	3	63.8	<0.50	21.9	9.5	13	0.8
0.10	1	41.1	<0.50	15.2	4	3.3	<0.50
	2	39	<0.50	14.8	4	3.3	<0.50
	3	34.8	<0.50	14.6	4	3.3	<0.50
0.50	1	35.9	<0.50	0.8	<0.50	<0.50	<0.50
	2	34.3	<0.50	0.7	<0.50	<0.50	<0.50
	3	31.6	<0.50	0.7	<0.50	<0.50	<0.50
1.0	1	23.3	<0.50	<0.50	<0.50	<0.50	<0.50
	2	23.1	<0.50	<0.50	<0.50	<0.50	<0.50
	3	24.8	<0.50	<0.50	<0.50	<0.50	<0.50
Elutriate		63	<10	16.3	7.1	13.8	0.7
Sediment		<21000	1200	2000	3560	23410	1500

Note: See Table 2 of main text for VOC CAS numbers and long and short names.

Table B4. GAC batch VOC concentrations (µg/L) and sediment concentration (µg/kg).

GAC dose (g/L)	Rep	VOC					
		Acetone	CH ₂ Cl ₂	Benzene	Toluene	Total Xylenes	Ethylbenzene
0.01	1	55.8	<0.50	18.2	11.4	27.1	1.5
	2	66.1	<0.50	18.9	11.9	28.8	1.6
	3	60.8	<0.50	17.2	10.8	27	1.5
0.05	1	38.3	<0.50	14.5	8.4	21.3	1.1
	2	33.6	<0.50	14.9	8.6	20.8	1.1
	3	31.4	<0.50	13.2	7.9	20	1
0.10	1	26.2	<0.50	5.8	2.3	5.2	<0.50
	2	27	<0.50	5.6	2.2	4.9	<0.50
	3	26.7	<0.50	5.6	2.3	4.9	<0.50
0.50	1	48.1	<0.50	11.4	5.6	13.6	0.7
	2	48.6	<0.50	11.2	5.7	14	0.6
	3	50.6	<0.50	11.1	5.6	13.6	0.6
1.0	1	23.1	<0.50	3	0.9	1.4	<0.50
	2	24.4	<0.50	1.2	2.6	<0.50	<0.50
	3	22.6	<0.50	2.6	0.9	1.6	<0.50
Elutriate		63	<10	16.3	7.1	13.8	0.7
Sediment		<21000	1200	2000	3560	23410	1500

Note: See Table 2 of main text for VOC CAS numbers and long and short names.

Appendix C: Column Settling Data

Table C1. Indiana Harbor and Canal (IHC) sediment physical characteristics.

Characteristic	Value
Salinity, ppt	0
Specific Gravity	2.72 (from spreadsheet) 2.88 (from Geotech tests)
In Situ Solids Concentration	
Water content, %	112.4 (from Geotech tests) 115.00 (from SETTLE)
Void ratio	3.128 (from SETTLE)
Solids concentration, g/L	658.9 (from spreadsheet)
Atterberg Limits	
Liquid Limit	82
Plastic Limit	38
Plasticity Index	44
Grain-Size Distribution	
Percent coarse (gravel, sand)	3.5 sand (Geotech tests) 0.2 (Coulter Counter)
Percent fines (silt, clay)	96.5 (Geotech tests) 99.8 (Coulter Counter)
Organic Matter, %	16.15 (from lab test)
Classification	Organic Clay (OH), Gray, Trace of Sand

Table C2. IHC initial total solids concentration of settling test slurry with no carbon (101.7 g/L Slurry).

Port height, ft	Total solids concentration, g/L
7.77	91.3
6.77	98.6
5.77	102.2
4.77	105.3
3.75	99.8
2.75	102.7
1.75	104.6
0.75	109.0
Average	101.7

Table C3. IHC zone settling test data with no carbon data (101.7 g/L slurry).

Elapsed time, hrs	Interface height, ft	Elapsed time, hrs	Interface height, ft
0	7.840	5.37	6.955
0.17	7.760	5.70	6.900
0.33	7.730	6.0	6.860
0.62	7.690	6.35	6.800
0.87	7.650	6.67	6.759
1.0	7.625	7.07	6.699
1.35	7.588	7.43	6.640
1.62	7.550	7.73	6.592
2.03	7.482	8.03	6.550
2.32	7.435	8.33	6.500
2.60	7.390	9.05	6.390
2.95	7.335	10.07	6.230
3.23	7.292	11.0	6.080
3.55	7.235	12.12	5.880
3.97	7.155	14.50	5.487
4.32	7.118	16.00	5.201
4.72	7.050	23.80	3.810
5.02	7.010	27.50	3.533

Table C4. IHC compression settling test with no carbon data (101.7 g/L slurry).

Elapsed time, days	Interface height, ft	Solids concentration, g/L
1	3.810	209.272
1.15	3.533	225.680
1.23	3.498	227.938
1.56	3.399	234.577
2.0	3.271	243.757
2.25	3.219	247.694
2.59	3.151	253.040
3.01	3.092	257.868
3.29	3.045	261.848
3.57	2.997	266.042
4.0	2.946	270.648
4.44	2.893	275.606
5.26	2.814	283.343
5.61	2.787	286.088
6.17	2.749	290.043
6.53	2.726	292.490
7.00	2.692	296.184
7.29	2.678	297.733
8.18	2.629	303.282
8.96	2.589	307.968
9.29	2.568	310.486
9.96	2.548	312.923
10.25	2.531	315.025
11.0	2.499	319.059
12.36	2.455	324.777
13.05	2.435	327.445
13.59	2.422	329.202
13.97	2.415	330.157
14.30	2.409	330.979
15.18	2.385	334.309
15.98	2.375	335.717

Table C5. IHC flocculent settling test with no carbon TSS and turbidity data (101.7 g/L slurry).

Time hr	Port ht ft	Turbidity NTU	TSS mg/L	Time hr	Port ht ft	Turbidity NTU	TSS mg/L
1	7.77	1357.0	506.7	96	7.27	130.0	116.0
2	7.77	861.0	373.3		6.77	131.0	102.0
4	7.77	395.0	200.0		6.27	129.0	94.0
	7.27	588.0	300.0		5.77	129.0	114.0
7	7.27	411.0	246.7		5.27	128.0	106.0
	6.77	408.0	213.3		4.77	127.0	114.0
12	7.27	280.0	176.2	168	6.77	115.0	98.0
	6.77	259.0	181.0		6.27	118.0	100.0
	6.27	252.0	147.6		5.77	114.0	94.0
24	7.27	178.0	128.0		5.27	115.0	104.0
	6.77	178.0	116.0		4.77	114.0	96.0
	6.27	174.0	120.0		4.27	114.0	104.0
	5.77	181.0	128.0	264	6.77	102.0	92.0
	5.27	167.0	120.0		6.27	103.0	80.0
	4.77	173.0	128.0		5.77	103.0	88.0
	4.27	167.0	104.0		5.27	102.0	90.0
48	7.27	152.0	112.0		4.77	99.5	94.0
	6.77	149.0	108.0		4.27	101.0	96.0
	6.27	155.0	128.0	384	6.77	92.0	53.3
	5.77	154.0	124.0		6.27	90.2	10.7
	5.27	159.0	112.0		5.77	91.4	73.3
	4.77	159.0	64.0		5.27	91.0	86.7
72	7.27	135.0	120.0		4.77	90.9	76.0
	6.77	134.0	114.0		4.27	90.2	98.7
	6.27	133.0	112.0				
	5.77	135.0	94.0				
	5.27	137.0	92.0				
	4.77	133.0	100.0				

Table C6. IHC flocculent settling test with no carbon smoothed TSS data for input into SETTLE (101.7 g/L slurry).

Time hr	Suspended solids concentration, mg/L							
	Port height, ft							
	7.77	7.27	6.77	6.27	5.77	5.27	4.77	4.27
1	506.7							
2	373.0							
4	200.0	300.0						
7		246.7	213.3					
12		176.2	181.0	147.6				
24		128.0	116.0	120.0	128.0	120.0	128.0	104.0
48		120.0	114.0	128.0	124.0	112.0	64.0	
72		116.0	108.0	112.0	114.0	92.0	100.0	
96		102.0	102.0	104.0	94.0	106.0	114.0	
168			98.0	100.0	94.0	104.0	96.0	104.0
264			92.0	80.0	88.0	90.0	94.0	96.0
384			53.3	70.7	73.3	86.7	76.0	98.7

Table C7. IHC 15-day column settling test with initial total solids concentration of 76.8 g/L and no carbon—initial total solids.

Port height, ft	Total solids concentration, g/L
5.045	75.4
4.045	77.0
3.045	78.0
2.045	77.1
1.045	76.7
Average	76.8

Table C8. IHC zone settling test with no carbon data (76.8 g/L slurry).

Elapsed time, hrs	Interface height, ft	Elapsed time, hrs	Interface height, ft
0.0	5.84	4.50	4.369
0.25	5.715	4.82	4.279
0.50	5.617	5.08	4.199
0.77	5.570	5.35	4.122
1.02	5.443	5.63	4.039
1.27	5.352	5.97	3.949
1.62	5.249	6.25	3.865
1.87	5.153	6.50	3.785
2.12	5.098	6.85	3.695
2.37	5.002	7.18	3.589
2.67	4.899	7.72	3.442
2.92	4.830	8.62	3.175
3.18	4.739	9.22	3.015
3.43	4.668	10.28	2.749
3.82	4.561	12.12	2.425
4.23	4.425		

Table C9. IHC compression settling test with no carbon data (76.8 g/L slurry).

Elapsed time, days	Interface height, ft	Solids concentration, g/L
1.00	2.119	211.662
1.18	2.059	217.830
1.46	1.969	227.787
2.00	1.845	243.096
2.46	1.771	253.254
3.00	1.689	265.549
3.46	1.645	272.652
4.00	1.601	280.145
4.46	1.571	285.495
4.98	1.539	291.431
5.47	1.518	295.462
5.98	1.499	299.207
6.47	1.479	303.254
7.00	1.458	307.621
7.47	1.458	307.621
8.00	1.430	313.645
8.46	1.421	315.631
9.00	1.411	317.868
9.44	1.399	320.595
10.01	1.391	322.439
10.44	1.381	324.773
11.00	1.373	326.666
11.48	1.368	327.860
11.97	1.361	329.546
12.48	1.355	331.005
13.00	1.349	332.477
13.33	1.349	332.477
13.99	1.342	334.212
14.48	1.338	335.211
15.00	1.332	336.721

Table C10. IHC flocculent settling test with no carbon tss and turbidity data (76.8 g/L slurry).

Time hr	Port ht ft	Turbidity NTU	TSS mg/L	Time hr	Port ht ft	Turbidity NTU	TSS mg/L
1.02	5.545	609	280.0	72	5.045	109	72.0
2.12	5.545	455	233.3		4.545	109	66.0
4.23	5.545	310	173.3		4.045	119	68.0
	5.045	309	173.3		3.545	114	74.0
	4.545	286	186.7		3.045	114	78.0
7.18	5.545	228	120.0		2.545	113	72.0
	5.045	223	125.0	96	5.045	103	70
	4.545	225	132.5		4.545	105	62
	4.045	214	117.5		4.045	105	62
12.12	5.545	162	97.5		3.545	105	56
	5.045	166	90.0		3.045	101	66
	4.545	160	100.0		2.545	102	62
	4.045	163	105.0	168	5.045	68.1	60
	3.545	172	110.0		4.545	78.2	62.9
	3.045	177	117.5		4.045	81.6	64.3
24	5.545	114	70.0		3.545	82.3	58.6
	5.045	136	84.0		3.045	79.8	61.4
	4.545	144	82.0		2.545	79.8	58.6
	4.045	142	84.0	264	4.545	79.0	38.6
	3.545	142	90.0		4.045	79.4	54.3
	3.045	140	88.0		3.545	78.5	58.6
48	5.045	126	88.0		3.045	78.5	52.9
	4.545	130	82.0		2.545	76.9	51.4
	4.045	127	76.0		2.045	79.6	57.1
	3.545	130	76.0	360	4.545	79.4	56.7
	3.045	127	82.0		4.045	79.6	57.8
	2.545	129	84.0		3.545	80.5	55.6
					3.045	80.8	57.8
					2.545	78.7	56.7
					2.045	79.0	57.8

Table C11. IHC flocculent settling test with no carbon smoothed data for input to SETTLE (76.8 g/L slurry).

Time hr	Suspended solids concentration, mg/L							
	Port height, ft							
	5.545	5.045	4.545	4.045	3.545	3.045	2.545	2.045
1.02	280.0							
2.12	233.3							
4.23	173.3	173.3	186.7					
7.18	120.0	125.0	132.5	117.5				
12.12	97.5	90.0	100.0	105.0	110.0	117.5		
24	70.0	84.0	82.0	84.0	90.0	88.0		
48		88.0	82.0	76.0	76.0	82.0	84.0	
72		72.0	66.0	68.0	74.0	78.0	72.0	
96		70.0	62.0	62.0	56.0	66.0	62.0	
168		60.0	62.9	64.3	58.6	61.4	58.6	
264			58.6	54.3	58.6	58.9	51.4	57.1
360			56.7	57.8	55.6	57.8	56.7	57.8

Table C12. IHC 15-day column settling test with initial total solids concentration of 101.9 g/L and 1 % carbon initial total solids.

Port height, ft	Total solids concentration, g/L
6.77	98.0
5.77	99.9
4.77	98.9
3.75	100.2
2.75	102.4
1.75	105.0
0.75	109.1
Average	101.9

Table C13. IHC zone settling test 101.9 g/L slurry with 1 % carbon.

Elapsed time, hrs	Interface height, ft	Elapsed time, hrs	Interface height, ft
0	7.698	5.60	6.832
0.08	7.675	5.90	6.789
0.25	7.642	6.17	6.752
0.50	7.598	6.43	6.712
0.75	7.562	6.68	6.675
1.00	7.530	7.10	6.611
1.25	7.495	7.33	6.578
1.50	7.462	7.58	6.539
1.77	7.424	7.83	6.508
2.03	7.384	8.12	6.462
2.25	7.349	8.57	6.394
2.50	7.309	9.10	6.312
2.75	7.268	9.23	6.292
3.08	7.212	10.18	6.149
3.42	7.165	11.37	5.968
3.50	7.122	12.12	5.849
3.93	7.082	13.07	5.698
4.23	7.032	13.93	5.554
4.53	6.989	22.63	4.031
4.78	6.952	23.32	3.940
5.07	6.915	24.63	3.742
5.33	6.875	25.87	3.615

Table C14. IHC compression settling test 101.9 g/L slurry with 1 % carbon data.

Elapsed time, days	Interface height, ft	Solids concentration, g/L
1.03	3.742	209.628
1.08	3.615	216.992
1.10	3.589	218.564
1.12	3.574	219.481
1.16	3.559	220.406
1.28	3.499	224.186
2.14	3.254	241.065
2.36	3.219	243.686
2.92	3.105	252.633
2.95	3.095	253.449
3.45	3.022	259.572
3.93	2.959	265.098
3.96	2.952	265.727
4.26	2.918	268.823
4.54	2.882	272.181
4.96	2.840	276.206
5.45	2.798	280.352
5.99	2.749	285.350
6.50	2.708	289.670
7.17	2.669	293.903
7.40	2.651	295.898
7.93	2.623	299.057
8.28	2.599	301.818
9.10	2.559	306.536
9.57	2.534	309.560
9.94	2.519	311.404
10.27	2.502	313.520
10.95	2.478	316.556
11.28	2.467	317.968
11.92	2.439	321.618
12.46	2.422	323.875
12.94	2.409	325.623
13.44	2.398	327.117
13.92	2.385	328.900
14.23	2.379	329.729
14.94	2.361	332.243

Table C15. IHC flocculent settling test 101.9 g/L slurry with 1 % carbon TSS and turbidity data.

Time hr	Port ht ft	Turbidity NTU	TSS mg/L	Time hr	Port ht ft	Turbidity NTU	TSS mg/L
3.08	7.27	172.0	106.7	95	4.77	38.3	50.0
5.07	7.27	137.0	106.0		4.27	37.2	42.5
7.10	7.27	107.0	114.0		3.75	36.8	41.3
	6.77	114.0	108.0		3.5	37.4	47.5
9.23	7.27	80.2	72.0		3.25	40.7	50.0
	6.77	94.3	88.0		3.0	41.4	48.8
12.12	7.27	67.2	86.0	172.02	6.27	34.2	47.8
	6.77	71.6	78.0		5.77	34.4	51.1
	6.27	63.6	80.0		5.27	34.5	56.7
26.47	7.27	54.5	73.3		4.77	34.3	50.0
	6.77	51.5	65.3		4.27	34.3	51.1
	6.27	52.2	66.7		3.75	35.2	50.0
	5.77	51.5	70.7		3.5	34.1	60.0
	5.27	52.5	64.0		3.25	34.2	62.2
	4.77	51.1	64.0		3.0	35.4	58.9
	4.27	50.1	77.3		2.75	34.3	57.8
	3.75	49.7	70.7	262.77	6.27	35.7	44.4
51.47	7.27	35.8	58.0		5.77	36.2	42.2
	6.77	45.2	63.0		5.27	35.9	30.0
	6.27	43.8	67.0		4.77	36.2	38.9
	5.77	44.2	64.0		4.27	36.3	35.6
	5.27	43.9	68.0		3.75	37.3	44.4
	4.77	46.9	66.0		3.5	37.1	45.6
	4.27	43.1	70.0		3.25	36.8	42.2
	3.75	44.9	60.0		3.0	37.3	47.8
	3.5	45.6	68.0		2.75	38.1	44.4
70.9	6.77	40.7	55.0		2.5	41.2	44.4
	6.27	39.9	52.5	358.63	6.27	40.2	46.7
	5.77	40.8	41.3		5.77	40.1	44.4
	5.27	39.8	32.5		5.27	40.0	38.9
	4.77	40.4	42.5		4.77	40.2	41.1
	4.27	40.0	48.8		4.27	39.9	44.4
	3.75	43.3	51.3		3.75	40.3	46.7
	3.5	41.9	46.2		3.5	41.0	53.3
	3.25	41.2	42.5		3.25	40.5	50.0
95	6.77	38.3	51.3		3.0	41.3	44.4
	6.27	37.0	43.8		2.75	41.8	52.2
	5.77	37.5	40.0		2.5	42.7	50.0
	5.27	38.2	37.5				

Table C16. IHC flocculent settling test 101.9 g/L slurry with 1 % carbon smoothed data for input to SETTLE.

Time hr	Suspended solids concentration, mg/L												
	Port height, ft												
	7.27	6.77	6.27	5.77	5.27	4.77	4.27	3.75	3.5	3.25	3.0	2.75	2.5
3.08	186.7												
5.07	156.0												
7.10	108.0	114.0											
9.23	102.0	105.0											
12.12	86.0	78.0	80.0										
26.47	65.3	73.3	66.7	70.7	64.0	64.0	77.3	70.7					
51.47	58.0	63.0	67.0	64.0	68.0	66.0	70.0	60.0	68.0				
70.9		55.0	52.5	41.3	47.5	42.5	48.8	51.3	46.2	48.5			
95.0		51.3	43.8	45.0	45.5	50.0	42.5	41.3	47.5	50.0	48.8		
172.02			41.8	41.1	46.7	40.0	41.1	40.0	50.0	52.2	48.9	47.8	
262.77			44.4	42.2	41.0	38.9	42.6	44.4	45.6	42.2	47.8	44.4	44.4
358.63			36.7	34.4	38.9	41.1	44.4	46.7	43.3	50.0	44.4	42.2	50.0

Table C17. IHC 15-day column settling test with initial total solids concentration of 78.6 g/L and 5 % carbon—initial total solids.

Port height, ft	Total solids concentration, g/L
5.48	72.0
4.48	78.6
3.48	76.7
2.48	77.5
1.48	81.7
0.48	84.8
Average	78.6

Table C18. IHC zone settling test 78.6 g/L slurry with 5 % carbon data.

Elapsed time, hrs	Interface height, ft	Elapsed time, hrs	Interface height, ft
0.0	5.783	4.25	4.383
0.25	5.648	4.50	4.305
0.50	5.550	4.77	4.225
0.75	5.439	5.18	4.109
1.02	5.372	5.43	4.029
1.35	5.289	5.68	3.972
1.60	5.179	5.93	3.887
1.92	5.089	6.28	3.795
2.18	4.998	6.57	3.712
2.43	4.918	6.83	3.662
2.67	4.849	7.22	3.519
2.92	4.765	7.78	3.352
3.18	4.695	9.07	2.984
3.43	4.618	9.65	2.829
3.68	4.539	10.75	2.579
4.02	4.449	12.27	2.449

Table C19. IHC compression settling test 78.6 g/L slurry with 5 % carbon data.

Elapsed time, days	Interface height, ft	Solids concentration, g/L
1.00	2.159	210.534
1.20	2.078	218.741
1.48	1.998	227.499
2.00	1.892	240.245
2.47	1.788	254.219
3.00	1.713	265.350
3.48	1.659	273.987
4.00	1.612	281.975
4.48	1.579	287.868
5.00	1.548	293.633
5.49	1.521	298.845
5.99	1.501	302.827
6.49	1.481	306.917
7.00	1.465	310.269
7.49	1.449	313.695
8.00	1.435	316.755
8.48	1.423	319.426
9.00	1.415	321.232
9.46	1.408	322.829
10.02	1.399	324.906
10.45	1.391	326.775
11.01	1.381	329.141
11.49	1.381	329.141
11.99	1.369	332.026
12.49	1.361	333.978
13.02	1.359	334.469
13.34	1.358	334.716
14.01	1.353	335.953
14.50	1.348	337.199
15.00	1.342	338.706

Table C20. IHC flocculent settling test 78.6 g/L slurry with 5 % carbon TSS and turbidity data.

Time hr	Port Ht ft	Turbidity NTU	TSS mg/L	Time hr	Port Ht ft	Turbidity NTU	TSS mg/L
1.02	5.48	579.0	260.0	72	4.98	89.7	50.0
1.92	5.48	355.0	180.0		4.48	90.2	58.0
4.02	5.48	225.0	123.3		3.98	89.5	58.0
	4.98	256.0	146.7		3.48	89.2	56.0
	4.48	253.0	130.0		2.98	88.6	46.0
7.22	5.48	163.0	92.0		2.48	86.1	52.0
	4.98	177.0	104.4	96	4.98	81.1	60.0
	4.48	189.0	104.4		4.48	79.1	53.3
	3.98	179.0	111.1		3.98	79.3	50.0
12.27	5.48	131.0	100.0		3.48	79.9	48.3
	4.98	132.0	84.4		2.98	78.9	48.3
	4.48	127.0	82.2		2.48	79.6	51.7
	3.98	129.0	88.9	168	4.98	66.4	46.0
	3.48	140.0	108.9		4.48	69.4	40.0
	2.98	135.0	111.1		3.98	71.0	46.7
	2.48	148.0	108.9		3.48	69.1	41.1
24	4.98	104.0	74.0		2.98	69.8	40.0
	4.48	118.0	70.0		2.48	67.6	43.3
	3.98	115.0	74.0	264	4.48	68.9	46.7
	3.48	117.0	72.0		3.98	68.0	48.9
	2.98	116.0	72.0		3.48	67.6	45.6
	2.48	124.0	76.0		2.98	69.0	50.0
48	4.98	95.8	64.0		2.48	68.6	50.0
	4.48	97.8	52.0		1.98	68.5	46.7
	3.98	105.0	62.0	360	4.48	63.0	38.9
	3.48	97.1	62.0		3.98	65.2	44.4
	2.98	100.0	62.0		3.48	67.7	43.3
	2.48	102.0	66.0		2.98	66.4	44.4
					2.48	65.5	44.4
					1.98	65.7	44.4

Table C21. IHC flocculent settling test 78.6 g/L slurry with 5 % carbon smoothed data for input to SETTLE.

Time hr	Suspended solids concentration, mg/L							
	Port height, ft							
	5.48	4.98	4.48	3.98	3.48	2.98	2.48	1.98
1.02	260.0	μμμμ						
1.92	180.0							
4.02	123.3	146.7	130.0					
7.22	92.0	104.4	104.4	111.1				
12.27	100.0	84.4	82.2	88.9	108.9	111.1	108.9	
24		74.0	70.0	74.0	72.0	72.0	76.0	
48		57.0	59.0	62.0	62.0	62.0	66.0	
72		50.0	58.0	58.0	56.0	46.0	52.0	
96		60.0	53.3	50.0	48.3	48.3	51.7	
168		46.0	49.0	46.7	47.1	48.0	50.3	
264			46.7	46.9	45.6	46.0	50.0	46.7
360			38.9	44.4	43.3	44.4	44.4	44.4

Appendix D: Laboratory Volatilization Data

Table D1. Laboratory data and flux calculations for unamended exposed sediment (PAHs – traps).

Exposed Sediment Unamended																			
OID 08896286																			
Volume extract collected = 2 mL																			
Liquid surface area = 375 cm ²																			
Trap concentrations																			
Test	PAC Conc.	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene			
				µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr		
ESU-P	0	2	2	372	992	33.2	88.5	12.1	32.3	2.80	7.47	8.10	21.6	2.80	7.47	0.640	1.71		
ESU-P	0	6	4	488	651	67.1	89.5	25.3	33.7	8.60	11.5	24.2	32.3	10.1	13.5	3.40	4.53		
ESU-P	0	24	18	1010	299	151	44.7	64.4	19.1	32.1	9.51	99.2	29.4	44.9	13.3	17.3	5.13		
ESU-P	0	48	24	237	52.7	66.0	14.7	36.2	8.04	27.1	6.02	95.8	21.3	50.5	11.2	23.1	5.13		
ESU-P	0	96	48	57.9	6.43	17.0	1.89	23.5	2.61	18.4	2.04	166	18.4	75.4	8.38	11.0	1.22		
ESU-P	0	168	72	17.8	1.32	10.9	0.807	14.0	1.04	10.1	0.748	197	14.6	83.4	6.18	6.60	0.489		
Flux = PAH concentration (µg/mL) * (2 mL) * (1000 ng/µg)/(375 cm ²)/(Elapsed time (hr))																			
				mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg			
Unamended (exposed) sediment				1190		207		90.7		65.1		271		275		756			
Test	PAC Conc.	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-anthracene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]-pyrene	Indeno- [1,2,3-cd]-pyrene	Dibenz- [a,h]anthracene	Benzo[ghi, h]- perylene	2-Fluoro- biphenyl	Terphenyl- d14
				µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	Surrogate %
ESU-P	0	2	2	0.200	0.533			0.030	0.080	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
ESU-P	0	6	4	1.00	1.33			0.100	0.133	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
ESU-P	0	24	18	5.40	1.60			0.480	0.142	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
ESU-P	0	48	24	8.30	1.84			0.870	0.193	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
ESU-P	0	96	48	16.8	1.87			2.00	0.222	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
ESU-P	0	168	72	21.4	1.59			2.90	0.215	0.031	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		
Flux = PAH concentration (µg/mL) * (2 mL) * (1000 ng/µg)/(375 cm ²)/(Elapsed time (hr))																			
				mg/kg		mg/kg		mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Unamended (exposed) sediment				273		544		368		212	172	117	110	152	94.9	16.6	83.6	127	96.2

Table D2. Laboratory data and flux calculations for unamended exposed sediment (VOCs – traps).

Exposed Sediment Unamended - VOAs																	
OID 08896286																	
Liquid surface area = 375 cm²																	
Trap concentrations																	
Test	PAC Conc.	Time from Start	Elapsed Time	Acetone		Methylene Chloride		Benzene		Toluene		Ethylbenzene		m,p-Xylene		o -Xylene	
				ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr	ng/tube	ng/cm²/hr
ESU - V	0	0.5	0.5	< 500	<2.67	3250	17.3	3200	17.07	8920	47.6	1580	8.43	16350	87.2	3750	20.0
ESU - V	0	1	0.5	< 500	<2.67	4090	21.8	2650	14.13	6220	33.2	1010	5.39	10730	57.2	2600	13.9
ESU - V	0	2	1	< 500	<1.33	5470	14.6	1180	3.15	2850	7.60	630	1.68	6750	18.0	1740	4.64
ESU - V	0	4	2	< 500	<0.667	7860	10.5	580	0.77	970	1.29	260	0.347	2910	3.88	960	1.28
ESU - V	0	6	2	< 500	<0.667	5160	6.88	570	0.76	1030	1.37	270	0.360	3220	4.29	1030	1.37
ESU - V	0	24	18	< 500	<0.074	3770	0.56	260	0.04	460	0.068	100	0.015	1080	0.160	380	0.056
ESU - V	0	48	24	< 500	<0.056	230	0.026	180	0.02	290	0.032	<100	<0.011	670	0.074	260	0.029
ESU - V	0	96	48	< 500	<0.028	26760	1.49	<100	<0.006	150	0.01	<100	<0.006	820	0.046	370	0.021
ESU - V	0	168	72	<500	<0.019	2500	0.093	<100	<0.004	<100	<0.004	<100	<0.004	240	0.009	100	0.004
					µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg
Unamended (exposed) sediment					<10000		<500		5920		8050		1300		15600		5260

Table D3. Laboratory data and flux calculations for PAC/GAC amended exposed sediment (PAHs – traps 1 of 2).

Exposed Sediment Amended OID 08896286 Volume extract collected = 2 mL Liquid surface area = 375 cm ² Trap concentrations																	
Test	Carbon Conc.	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene	
	mg/g sed.	hrs	hrs	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr
ESA-1	5 PAC	2	2	135	360	12.7	33.9	5.76	15.4	2.13	5.68	1.93	5.15	1.21	3.23	0.4	1.07
ESA-1	5 PAC	6	4	92.1	123	26.6	35.5	11.5	15.3	4.72	6.29	4.47	5.96	3.2	4.27	1.22	1.63
ESA-1	5 PAC	24	18	12.8	3.79	8.11	2.40	10.6	3.14	8.06	2.39	13.7	4.06	9.5	2.81	3.05	0.904
ESA-1	5 PAC	48	24	5.93	1.32	3.02	0.671	3.23	0.718	2.75	0.611	9.55	2.12	5.27	1.17	1.35	0.300
ESA-1	5 PAC	96	48	4.98	0.553	3.66	0.407	3.18	0.353	3.12	0.347	11.5	1.28	8.91	0.990	3.0	0.331
ESA-1	5 PAC	168	72	2.98	0.221	2.85	0.211	2.68	0.199	3.63	0.269	13.3	0.985	12.4	0.919	4.71	0.349
ESA-2	5 GAC	2	2	157	419	23.8	63.5	8.92	23.8	3.19	8.51	2.56	6.83	1.65	4.40	0.55	1.47
ESA-2	5 GAC	6	4	93.5	125	32.9	43.9	14.3	19.1	7.82	10.4	6.79	9.05	4.69	6.25	1.68	2.24
ESA-2	5 GAC	24	18	17.4	5.16	12	3.56	16.7	4.95	14	4.15	24.4	7.23	16.6	4.92	4.56	1.35
ESA-2	5 GAC	48	24	6.71	1.49	3.41	0.758	3.82	0.849	3.84	0.853	16.5	3.67	9.2	2.04	1.55	0.344
ESA-2	5 GAC	96	48	4.32	0.480	3.37	0.374	3.95	0.439	4.08	0.453	24.7	2.74	16.7	1.86	3.04	0.338
ESA-2	5 GAC	168	72	1.84	0.136	1.94	0.144	2.24	0.166	3.39	0.251	25.6	1.90	19.3	1.43	3.71	0.275
ESA-3	10 GAC	2	2	465	1240	67.9	181	26.2	69.9	11.4	30.4	9.89	26.4	5.68	15.1	1.24	3.31
ESA-3	10 GAC	6	4	492	656	138	184	56.2	74.9	33	44.0	28.5	38.0	20.9	27.9	7.45	9.93
ESA-3	10 GAC	24	18	65.2	19.3	65.8	19.5	64.1	19.0	27.3	8.09	90.6	26.8	69.8	20.7	29.8	8.83
ESA-3	10 GAC	48	24	23.2	5.16	16.9	3.76	18	4.00	16.1	3.58	73.5	16.3	45.3	10.1	12.6	2.80
ESA-3	10 GAC	96	48	9.2	1.02	10.6	1.18	10.9	1.21	12.8	1.42	82.8	9.20	79.4	8.82	15.8	1.76
ESA-3	10 GAC	168	72	3.68	0.273	5.41	0.401	6.46	0.479	11.8	0.874	94.6	7.01	85.1	6.30	21.6	1.60
ESA-4	50 GAC	2	2	51.2	137	13.6	36.3	6.42	17.1	2.34	6.24	2.13	5.68	1.53	4.08	0.49	1.31
ESA-4	50 GAC	6	4	28.80	38.4	17.2	22.9	9.82	13.1	4.85	6.47	4.53	6.04	3.6	4.80	1.61	2.15
ESA-4	50 GAC	24	18	4.6	1.36	6.88	2.04	13	3.85	10.8	3.20	16.4	4.86	11.1	3.29	3.79	1.12
ESA-4	50 GAC	48	24	2.52	0.560	1.36	0.302	2.81	0.624	3.01	0.669	10.6	2.36	5.11	1.14	1.46	0.324
ESA-4	50 GAC	96	48	2.06	0.229	1.07	0.119	1.78	0.198	2.18	0.242	13.2	1.47	7.04	0.782	2.48	0.276
ESA-4	50 GAC	168	72	1.77	0.131	1	0.074	1.28	0.095	1.74	0.129	13.6	1.01	7.82	0.579	3.46	0.256
				mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg	
ESA-1	0	Sediment (bulk)		178		46		20.8		33.9		31.4		61		140	
ESA-2	0	Sediment (bulk)		125		42.4		20.4		25.8		31		56		137	
ESA-3	0	Sediment (bulk)		360		142		70.6		131		171		289		832	
ESA-4	0	Sediment (bulk)		143		34.8		17		18.9		24.1		43.2		109	

Table D4. Laboratory data and flux calculations for PAC/GAC amended exposed sediment (PAHs – traps 2 of 2).

Exposed Sediment Amended OID 08896286 Volume extract collected = 2 mL Liquid surface area = 375 cm ² Trap concentrations																	
Test	Carbon Conc.	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-anthracene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]-pyrene	Indeno[1,2,3-cd]-pyrene	Dibenz[a,h]anthracene	Benzo[g,h,i]perylene
	mg/g sed.	hrs	hrs	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
ESA-1	5 PAC	2	2	0.08	0.213	0	0.000	0.03	0.080	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-1	5 PAC	6	4	0.31	0.413	0.07	0.093	0.29	0.387	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-1	5 PAC	24	18	1.58	0.468	0.56	0.166	0.29	0.086	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-1	5 PAC	48	24	1.16	0.258	0.6	0.133	0.78	0.173	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-1	5 PAC	96	48	2.27	0.252	1.58	0.176	1.2	0.137	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-1	5 PAC	168	72	3.22	0.239	2.55	0.189	2.9	0.215	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	2	2	0.15	0.400	0	0.000	0	0.000	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	6	4	0.51	0.680	0.09	0.120	0.04	0.053	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	24	18	2.8	0.830	0.63	0.187	0.35	0.104	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	48	24	2.32	0.516	0.67	0.149	0.39	0.087	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	96	48	5.86	0.651	1.94	0.216	0.98	0.109	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-2	5 GAC	168	72	7.94	0.588	2.91	0.216	1.45	0.107	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	2	2	0.31	0.83	0	0.00	0	0.00	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	6	4	1.97	2.63	0.08	0.107	0.04	0.053	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	24	18	11	3.26	1.41	0.418	0.63	0.187	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	48	24	11.3	2.51	2.48	0.551	1.12	0.249	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	96	48	17.2	1.91	5.51	0.612	2.27	0.252	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-3	10 GAC	168	72	25.1	1.86	8.93	0.661	3.95	0.293	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	2	2	0.12	0.320	0	0.000	0	0.000	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	6	4	0.41	0.547	0.06	0.080	0	0.000	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	24	18	2.02	0.599	0.55	0.163	0.22	0.065	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	48	24	1.62	0.360	0.61	0.136	0.31	0.069	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	96	48	2.77	0.308	1.62	0.180	0.65	0.072	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
ESA-4	50 GAC	168	72	3.88	0.287	2.61	0.193	1.13	0.084	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
				mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg	
ESA-1	0	Sediment (bulk)		55.2		128		80.8		49		46		33.4		39.4	
ESA-2	0	Sediment (bulk)		56		123		84.4		49.3		44		27.5		35	
ESA-3	0	Sediment (bulk)		347		690		458		204		171		106		91.9	
ESA-4	0	Sediment (bulk)		40		105		69		40.5		38.3		25.5		22.4	

Table D5. Laboratory data and flux calculations for unamended sediment slurry (PAHs – traps 1 of 2).

Unamended Sediment Slurry Test (UST)																			
OID 08896284																			
Traps																			
Liquid surface area = 375 cm ²																			
Test	TSS	PAC	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene		
	mg/L	mg/L	hr	hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	
UST - 1 (Elutriate)	100	0	2	2	640	853	32.2	42.9	15.2	20.3	11.1	14.8	5.90	7.87	3.40	4.53	2.30	3.07	
	100	0	6	4	785	523	43.5	29.0	19.4	12.9	16.1	10.7	9.30	6.20	5.80	3.87	4.70	3.13	
	100	0	24	18	174	25.8	16.2	2.40	8.70	1.29	25.8	3.82	13.2	1.96	12.8	1.90	12.1	1.79	
	100	0	48	24	19.3	2.14	2.90	0.322	1.70	0.189	12.6	1.40	7.20	0.800	9.60	1.07	9.00	1.00	
	100	0	96	48	20.8	1.16	3.90	0.217	2.00	0.111	7.20	0.400	5.80	0.322	7.50	0.417	11.8	0.656	
UST - 2 (Elutriate)	350	0	2	2	650	867	38.6	51.5	17.5	23.3	11.9	15.87	8.30	11.1	3.70	4.93	1.80	2.40	
	350	0	6	4	510	340	33.4	22.3	16.4	10.9	16.1	10.73	11.2	7.47	5.20	3.47	3.00	2.00	
	350	0	24	18	392	58.1	44.9	6.65	20.8	3.08	52.0	7.70	34.0	5.04	20.6	3.05	13.5	2.00	
	350	0	48	24	54.0	6.00	8.20	0.911	5.30	0.589	25.2	2.80	24.2	2.69	22.0	2.44	13.2	1.47	
	350	0	96	48	33.0	1.83	5.00	0.278	2.50	0.139	7.90	0.439	11.6	0.644	11.6	0.644	7.40	0.411	
UST - 3 (Elutriate)	700	0	2	2	815	1087	56.2	74.9	22.8	30.4	10.7	14.27	14.0	18.7	4.80	6.40	2.10	2.80	
	700	0	6	4	848	565	77.2	51.5	31.4	20.9	18.4	12.27	25.2	16.8	9.40	6.27	4.90	3.27	
	700	0	24	18	560	83.0	87.0	12.9	38.2	5.66	39.8	5.90	55.8	8.27	25.4	3.76	16.6	2.46	
	700	0	48	24	70.8	7.87	18.8	2.09	13.8	1.53	28.4	3.16	55.6	6.18	31.6	3.51	17.6	1.96	
	700	0	96	48	40.4	2.24	9.80	0.54	5.00	0.278	9.30	0.517	27.0	1.50	8.70	0.483	3.20	0.178	
UST - 4 (DDI)	700	0	2	2	159	212	25.6	34.1	11.1	14.8	2.40	3.20	14.5	19.3	4.70	6.27	3.60	4.80	
	700	0	6	4	190	127	34.8	23.2	15.4	10.3	4.30	2.87	25.8	17.2	9.20	6.13	8.00	5.33	
	700	0	24	18	124	18.4	33.0	4.89	16.6	2.46	8.10	1.20	48.9	7.24	23.6	3.50	23.8	3.53	
	700	0	48	24	9.70	1.08	3.50	0.39	4.80	0.533	4.40	0.489	40.0	4.44	16.8	1.87	16.7	1.86	
	700	0	96	48	7.50	0.417	2.50	0.14	1.80	0.100	1.80	0.100	24.4	1.36	6.30	0.350	12.5	0.694	
Flux = PAH concentration (µg/mL) * (1000 ng/µg)/(375 cm ²)(Elapsed time (hr))																			
					mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		
UST		0	Sediment (bulk)		1140		219		82		361		271		893		309		

Table D6. Laboratory data and flux calculations for unamended sediment slurry (PAHs – traps 2 of 2).

Unamended Sediment Slurry Test (UST)																			
OID 08896284																			
Traps																			
Liquid surface area = 375 cm ²																			
Test	TSS	PAC	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-anthracene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]pyrene	Indeno[1,2,3-cd]pyrene	Dibenz[a,h]anthracene	Benzo[g,h,i]perylene	
	mg/L	mg/L	hr	hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	ng/cm ² /hr	µg/Sample	µg/Sample	µg/Sample	µg/Sample	µg/Sample	µg/Sample	µg/Sample	µg/Sample	
UST - 1 (Elutriate)	100	0	2	2	0.530	0.707	0.0800	0.107	<0.20	<0.267	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	100	0	6	4	1.20	0.800	0.240	0.160	0.120	0.0800	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	100	0	24	18	3.00	0.444	0.940	0.139	0.500	0.0741	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	100	0	48	24	3.80	0.422	2.00	0.222	1.100	0.122	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	100	0	96	48	4.30	0.239	6.00	0.333	3.200	0.178	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
UST - 2 (Elutriate)	350	0	2	2	0.420	0.560	<0.20	<0.267	<0.20	<0.267	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	350	0	6	4	0.780	0.520	0.150	0.100	<0.20	<0.133	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	350	0	24	18	3.60	0.533	0.720	0.107	0.360	0.0533	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	350	0	48	24	5.90	0.656	1.70	0.189	0.880	0.0978	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	350	0	96	48	6.40	0.356	3.80	0.211	1.900	0.106	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
UST - 3 (Elutriate)	700	0	2	2	0.430	0.573	<0.20	<0.267	<0.20	<0.267	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	6	4	1.20	0.800	0.100	0.0667	<0.20	<0.133	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	24	18	4.50	0.667	0.530	0.0785	0.210	0.0311	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	48	24	7.80	0.867	1.70	0.189	0.700	0.0778	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	96	48	4.20	0.233	1.80	0.100	0.770	0.0428	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
UST - 4 (DDI)	700	0	2	2	0.760	1.01	0.100	0.133	<0.20	<0.267	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	6	4	1.80	1.20	0.270	0.180	0.120	0.0800	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	24	18	5.50	0.815	1.30	0.193	0.580	0.0859	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	48	24	6.90	0.767	2.70	0.300	1.200	0.133	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
	700	0	96	48	3.00	0.167	5.70	0.317	2.700	0.150	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	
Flux = PAH concentration (µg/mL) * (1000 ng/µg)/(375 cm ²)(Elapsed time (hr))																			
					mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		
UST		0	Sediment (bulk)		553		415		189		210		243 I		163 J		98	29 J	
																		93	

Table D7. Laboratory data and flux calculations for unamended sediment slurry (VOCs – traps).

Unamended Sediment Slurry Test (UST)																		
Traps--VOAs																		
Simulated effluent prepared using a 100 g/L suspended solids concentration																		
3 liters of effluent loaded into chambers and sediment added to produce 3 suspended solids concentrations of 100, 350, and 700 mg/L																		
Liquid surface area = 375 cm²																		
Concentration in ng/tube (traps (Orbo 402, Supelco))																		
Test	TSS mg/L	PAC mg/L	Time from Start hrs	Elapsed Time hrs	Acetone		Methylene Chloride		Benzene		Toluene		Ethylene		m/p -Xylene		o - Xylene	
					ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr	ng/Sample	ng/cm²/hr
UST - 1 (Elutriate)	100	0	0.5	0.5	<500	< 2.67	11580	61.8	4220	22.5	11720	62.5	1900	10.1	9840	52.5	2300	12.3
	100	0	1	0.5	<500	< 2.67	11640	62.1	3440	18.3	9460	50.5	1460	7.79	7680	41.0	1940	10.3
	100	0	2	1	<500	< 1.33	9980	26.6	1280	3.41	3040	8.11	6800	18.1	3680	9.81	1080	2.88
	100	0	4	2	<500	< 0.67	14420	19.2	360	0.480	780	1.04	190	0.253	1200	1.60	480	0.640
	100	0	6	2	<500	< 0.67	17040	22.7	140	0.187	340	0.453	< 100	< 0.133	560	0.747	220	0.293
	100	0	24	18	<500	< 0.07	5900	0.874	< 100	< 0.015	< 100	< 0.0148	< 100	< 0.0148	<200	< 0.03	< 100	< 0.0148
	100	0	48	24	<500	< 0.056	57800	6.422	< 100	< 0.011	< 100	< 0.011	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
100	0	96	48	<500	< 0.027	28400	1.58	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056	
UST - 2 (Elutriate)	350	0	0.5	0.5	<500	< 2.67	11740	62.6	4480	23.9	13740	73.3	2240	11.9	12940	69.0	3120	16.6
	350	0	1	0.5	<500	< 2.67	14400	76.8	2880	15.4	8260	44.1	1260	6.72	7500	40.0	1900	10.1
	350	0	2	1	<500	< 1.33	8560	22.8	1100	2.93	2800	7.47	660	1.76	4020	10.7	1120	2.99
	350	0	4	2	<500	< 0.67	10400	13.9	320	0.427	620	0.827	150	0.200	1040	1.39	420	0.560
	350	0	6	2	<500	< 0.67	15940	21.3	110	0.147	260	0.347	< 100	< 0.133	560	0.747	220	0.293
	350	0	24	18	<500	< 0.07	43000	6.37	< 100	< 0.015	< 100	< 0.0148	< 100	< 0.0148	<200	< 0.03	< 100	< 0.0148
	350	0	48	24	<500	< 0.056	81600	9.07	< 100	< 0.011	< 100	< 0.011	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
350	0	96	48	<500	< 0.027	178800	9.93	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056	
UST - 3 (Elutriate)	700	0	0.5	0.5	<500	< 2.67	7340	39.1	2280	12.2	6380	34.0	1000	5.33	6320	33.7	1540	8.21
	700	0	1	0.5	<500	< 2.67	12420	66.2	3040	16.2	8120	43.3	1200	6.40	7720	41.2	1980	10.6
	700	0	2	1	<500	< 1.33	12360	33.0	1500	4.00	3660	9.76	860	2.29	5600	14.9	1580	4.21
	700	0	4	2	<500	< 0.67	12960	17.3	380	0.507	680	0.907	200	0.267	1420	1.89	540	0.720
	700	0	6	2	<500	< 0.67	16620	22.2	120	0.160	300	0.400	< 100	< 0.133	700	0.933	260	0.347
	700	0	24	18	<500	< 0.07	80400	11.9	< 100	< 0.015	160	0.213	< 100	< 0.0148	<200	< 0.03	< 100	< 0.0148
	700	0	48	24	<500	< 0.056	75800	8.42	< 100	< 0.011	< 100	< 0.011	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
700	0	96	48	<500	< 0.027	47000	2.61	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056	
UST - 4 (DDI)	700	0	0.5	0.5	<500	< 2.67	12900	68.8	1160	6.19	5120	27.3	1560	8.32	15500	82.7	3280	17.5
	700	0	1	0.5	<500	< 2.67	12760	68.1	360	1.92	1560	8.32	420	2.24	4560	24.32	1120	5.97
	700	0	2	1	<500	< 1.33	14820	39.5	160	0.427	800	2.13	320	0.853	3320	8.85	860	2.29
	700	0	4	2	<500	< 0.67	12800	17.1	<100	< 0.133	190	0.253	<100	< 0.133	840	1.12	280	0.373
	700	0	6	2	<500	< 0.67	84800	113	<100	< 0.133	150	0.200	< 100	< 0.133	640	0.853	180	0.240
	700	0	24	18	<500	< 0.07	4500	0.667	< 100	< 0.015	100	< 0.0148	< 100	< 0.0148	<200	< 0.03	< 100	< 0.0148
	700	0	48	24	<500	< 0.056	57400	6.38	< 100	< 0.011	< 100	< 0.011	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
700	0	96	48	<500	< 0.027	39000	2.17	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056	
					µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg	
UST	0			Sediment (bulk)	<25000		<1000		25400		24600		1890J		31300		9510	

Table D10. Laboratory data and flux calculations for PAC amended sediment slurry (PAHs – traps).

Amended Sediment Slurry Test (OID 08896284) Volume extract collected = 2 mL Slurry surface area = 375 cm ²																	
Test	PAC Conc.	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene	
	g/L	hr	hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr
AST	0.025	2	2	610	1,627	41.70	111.20	19.30	51.47	4.40	11.73	17.80	47.47	6.20	16.53	2.00	5.333
AST	0.050	2	2	20.9	55.7	13.30	35.47	5.90	15.73	2.30	6.13	9.00	24.00	2.60	6.93	0.55	1.467
AST	0.10	2	2	29.8	79.5	4.90	13.07	4.50	12.00	2.60	6.93	34.80	92.80	10.10	26.93	1.60	4.267
AST	0.025	6	4	9.30	12.4	15.50	20.67	11.20	14.93	8.20	10.93	39.70	52.93	15.50	20.67	4.50	6.000
AST	0.050	6	4	10.8	14.4	15.90	21.20	10.10	13.47	6.00	8.00	26.10	34.80	8.90	11.87	2.00	2.667
AST	0.10	6	4	15.3	20.4	12.60	16.80	8.80	11.73	6.60	8.80	28.90	38.53	10.40	13.87	2.30	3.067
AST	0.025	24	18	19.5	5.78	3.40	1.01	3.20	0.95	2.10	0.62	45.80	13.57	12.40	3.67	3.20	0.948
AST	0.050	24	18	45.7	13.5	11.70	3.47	8.90	2.64	4.50	1.33	45.70	13.54	13.80	4.09	2.60	0.770
AST	0.10	24	18	20.9	6.19	20.70	6.13	9.60	2.84	3.80	1.13	14.40	4.27	4.60	1.36	1.10	0.326
AST	0.025	48	24	10.2	2.27	1.50	0.33	0.92	0.20	0.57	0.13	6.80	1.51	6.40	1.42	3.60	0.800
AST	0.050	48	24	17.0	3.78	3.90	0.87	2.40	0.53	1.70	0.38	14.70	3.27	8.40	1.87	1.70	0.378
AST	0.10	48	24	17.5	3.89	2.60	0.58	1.60	0.36	1.00	0.22	8.60	1.91	5.80	1.29	1.10	0.244
AST	0.025	96	48	3.2	0.356	0.97	0.11	0.65	0.07	0.42	0.05	3.90	0.43	6.50	0.72	5.60	0.622
AST	0.050	96	48	7.5	0.833	2.00	0.22	1.30	0.14	1.00	0.11	7.80	0.87	5.50	0.61	1.30	0.144
AST	0.10	96	48	10.3	1.14	2.00	0.22	1.40	0.16	1.10	0.12	7.50	0.83	6.30	0.70	1.50	0.167
Flux = PAH concentration (µg/mL) * (2 mL) * (1000 ng/µg)/(375 cm ²)/(Elapsed time (hr))																	

Test	PAC Conc.	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-anthracene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]-pyrene	Indeno[1,2,3-cd]-pyrene	Dibenz[a,h]anthracene	Benzo[g,h,i]-perylene
	g/L	hr	hr	µg/mL	ng/cm ² /hr	µg/mL	ng/cm ² /hr	µg/mL	ng/cm ² /hr	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
AST	0.025	2	2	0.56	1.493	0.04	0.107	<.10	<0.267	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.050	2	2	0.16	0.427	<.10	<0.267	<.10	<0.267	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.10	2	2	2.10	5.600	0.93	2.480	0.44	1.173	<.10	<.10	<.10	<.10	<.10	ND	ND	ND
AST	0.025	6	4	2.40	3.200	0.31	0.413	0.13	0.173	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.050	6	4	0.89	1.187	0.07	0.093	0.04	0.053	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.10	6	4	1.20	1.600	0.13	0.173	0.06	0.080	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.025	24	18	3.40	1.007	2.70	0.800	1.20	0.356	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.050	24	18	2.90	0.859	0.78	0.231	0.37	0.110	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.10	24	18	0.34	0.101	<.10	<0.267	<.10	<0.267	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.025	48	24	1.10	0.244	3.80	0.844	2.20	0.489	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.050	48	24	1.50	0.333	1.40	0.311	0.67	0.149	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.10	48	24	1.00	0.222	1.80	0.400	0.91	0.202	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.025	96	48	1.50	0.167	7.50	0.833	4.20	0.467	0.04J	0.03J	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.050	96	48	0.96	0.107	1.30	0.144	0.64	0.071	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10
AST	0.10	96	48	1.30	0.144	3.40	0.378	1.80	0.200	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10

Table D11. Laboratory data and flux calculations for PAC-amended sediment slurry (VOCs – traps).

Amended Sediment/Slurry Test - VOAs																	
Simulated effluent prepared using a 100 g/L																	
suspended solids concentration																	
3 liters of unfiltered effluent loaded into glass jars (0																	
head space) and PAC added to produce 3																	
Jars with effluent/PAC slurry tumbled for 15 minutes.																	
Contents allowed to settle for 4 hours.																	
Supernatant decanted into flux chambers																	
Concentration in ng/tube (traps (Orbo 402, Supelco))																	
Test	PAC Conc.	Time from Start	Elapsed Time	Acetone		Dimethylenechloride		Benzene		Toluene		Ethylene		m/p - Xylene		o - Xylene	
	g/L	hrs	hrs	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr
AST-1	0.025	0.5	0.5	<500	< 2.67	8160	43.52	5220	27.84	9080	48.43	1700	9.07	16060	85.65	4320	23.04
AST-1	0.025	1	0.5	<500	< 2.67	8900	47.47	4240	22.61	7420	39.57	1340	7.15	13020	69.44	3560	18.99
AST-1	0.025	2	1	<500	< 1.33	6060	16.16	1720	4.59	2360	6.29	520	1.39	5180	13.81	1800	4.80
AST-1	0.025	4	2	<500	< 0.67	8840	11.79	760	1.01	1040	1.39	220	0.29	2580	3.44	1000	1.33
AST-1	0.025	6	2	<500	< 0.67	6420	8.56	480	0.64	980	1.31	300	< 0.133	3220	4.29	1220	1.63
AST-1	0.025	24	18	<500	< 0.07	11740	1.74	< 100	< 0.015	200	0.03	< 100	< 0.0148	200	0.03	< 100	< 0.0148
AST-1	0.025	48	24	<500	< 0.056	43000	4.78	< 100	< 0.011	120	0.01	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
AST-1	0.025	96	48	<500	< 0.027	33400	1.86	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056
AST-2	0.050	0.5	0.5	<500	< 2.67	15580	83.09	6000	32.00	11880	63.36	2160	11.52	20000	106.67	5320	28.37
AST-2	0.050	1	0.5	<500	< 2.67	9120	48.64	4580	24.43	7820	41.71	1380	7.36	13240	70.61	3620	19.31
AST-2	0.050	2	1	<500	< 1.33	8380	22.35	1920	5.12	2780	7.41	600	1.60	6280	16.75	2220	5.92
AST-2	0.050	4	2	<500	< 0.67	11460	15.28	740	0.99	1140	1.52	240	0.32	2660	3.55	1060	1.41
AST-2	0.050	6	2	<500	< 0.67	6740	8.99	700	0.93	1380	1.84	420	< 0.133	4140	5.52	1480	1.97
AST-2	0.050	24	18	<500	< 0.07	680	0.10	< 100	< 0.015	< 100	< 0.0148	< 100	< 0.0148	<200	< 0.03	< 100	< 0.0148
AST-2	0.050	48	24	<500	< 0.056	124200	13.80	< 100	< 0.011	< 100	< 0.011	< 100	< 0.011	<200	< 0.022	< 100	< 0.011
AST-2	0.050	96	48	<500	< 0.027	89800	4.99	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056
AST-3	0.10	0.5	0.5	<500	< 2.67	11260	60.05	4760	25.39	8260	44.05	1420	7.57	13720	73.17	3760	20.05
AST-3	0.10	1	0.5	<500	< 2.67	10140	54.08	4140	22.08	7340	39.15	1300	6.93	12840	68.48	3440	18.35
AST-3	0.10	2	1	<500	< 1.33	9200	24.53	1780	4.75	2640	7.04	620	1.65	6300	16.80	2240	5.97
AST-3	0.10	4	2	<500	< 0.67	11180	14.91	640	0.85	1080	1.44	220	0.29	2460	3.28	1020	1.36
AST-3	0.10	6	2	<500	< 0.67	7060	9.41	680	0.91	1500	2.00	500	< 0.133	4640	6.19	1560	2.08
AST-3	0.10	24	18	<500	< 0.07	780	0.12	< 100	< 0.015	180	0.03	< 100	< 0.0148	260	< 0.03	< 100	< 0.0148
AST-3	0.10	48	24	<500	< 0.056	52200	5.80	< 100	< 0.011	120	0.01	< 100	< 0.011	200	< 0.022	< 100	< 0.011
AST-3	0.10	96	48	<500	< 0.027	32600	1.81	< 100	< 0.0056	< 100	< 0.0056	< 100	< 0.0056	<200	< 0.011	< 100	< 0.0056
				µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg	
				Sediment concentration	<10000	<500		10000		9950		1370		16300		5320	

Table D12. Laboratory data for PAC-amended sediment slurry (PAHs – water).

Amended Sediment Slurry Test - PAHs (Water)														
Sample	PAC Conc.	Dilution	Sample	TSS	Napthalene	1-Methyl-napthalene	2-Methyl-napthalene	Acenaphylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	
	g/L			mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	
Initial Water Concentrations	AST-1	0.025	1:200	Total	1,090	2290 D	77.7 D	144 D	41.3 D	130 D	79.4 D	138 D	40.4 D	63.1 D
	AST-2*	0.050	1:4	Total	860	29.8	4.56	5.91	4.58	98.7 D	28.7	17	37.6	100 D
	AST-3	0.10	1:200	Total	1,020	2230 D	78.7 D	150 D	42.3 D	134 D	87.6 D	155 D	45.0 D	83.2 D
	AST-1	0.025	1:100	Dissolved		1280 D	43.0 D	75.2 D	27.7 D	73.1 D	44.7 D	51.8 D	14.9	13.2
	AST-2	0.050	1:100	Dissolved		1000 D	34.6 D	60.3 D	18.2	57.8 D	32.8	38.1	13.6	14.2
	AST-3	0.10	1:100	Dissolved		1240 D	42.7 D	75.2 D	26.6 D	69.3 D	39.9 D	47.9 D	13.8	12.3
Final Water Concentrations	AST-1	0.025	1:2	Total		17.5	0.95	2.4	1.33	2.17	2.27	5.09	3.41	36.2 D
	AST-2	0.050	1:2	Total		14.8	0.82	2.06	1.12	1.93	1.81	4.05	2.87	29.9 D
	AST-3	0.10	1:2	Total		16.1	0.94	2.38	1.27	2.37	2.2	4.94	3.28	34.6 D
	AST-1	0.025	na	Dissolved		0.24	.05 J	.08 J	0.38	0.14	0.14	0.24	1.32	10
	AST-2	0.050	na	Dissolved		0.1	u	0.04 J	0.33	0.1	0.16	0.15	1.33	8.95
	AST-3	0.10	na	Dissolved		0.11	0.05 J	0.05 J	0.36	0.29	0.21	0.08 J	1.2	9.36
Sample	PAC Conc.	Dilution	Sample	TSS	Pyrene	Benzo(a)-anthracene	Chrysene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Benzo(a)-pyrene	Indeno(1,2,3-cd)pyrene	Dibenzo(ah)-anthracene	Benzo(ghi)-perylene	
	g/L			mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	
Initial Water Concentrations	AST-1	0.025	1:200	Total	1,090	49.8 D	11.9	10.8	12.8 I	I	7.9	3.33	0.81	2.76
	AST-2*	0.050	1:4	Total	860	74.4 D	26.2	24.9	30.7 I	I	18.9	8.67	2.16	7.2
	AST-3	0.10	1:200	Total	1,020	61.9 D	17.3	17.1	21.4 I	I	13.4	6.3	1.61	5.3
	AST-1	0.025	1:100	Dissolved		7.21	1.61	1.43	1.24 I	I	0.73	0.23	0.06 J	0.19
	AST-2	0.050	1:100	Dissolved		7.94	2.09	1.89	1.65 I	I	0.98	0.27	U	0.23
	AST-3	0.10	1:100	Dissolved		6.68	1.52	1.38	1.20 I	I	0.73	0.23	0.06 J	0.19
Final Water Concentrations	AST-1	0.025	1:2	Total		27.3 D	8.82	7.98	9.4 I	I	5.75	2.48	0.6	2.08
	AST-2	0.050	1:2	Total		22.3 D	6.48	5.71	6.55 I	I	3.95	1.63	0.42	1.36
	AST-3	0.10	1:2	Total		26.2 D	8.64	7.68	9.53 I	I	5.8	2.46	0.6	2.05
	AST-1	0.025	na	Dissolved		5.75	1.31	1.12	0.83 I	I	0.47	0.1	u	0.09 J
	AST-2	0.050	na	Dissolved		4.91	1.11	0.93	0.70 I	I	0.4	0.05 J	u	0.08 J
	AST-3	0.10	na	Dissolved		5.3	1.29	1.09	0.82 I	I	0.47	0.11	u	0.09 J

I: Compound analyzed for but not detected at or above the sample report limit
 J: Estimated concentration above MDL (0.04 µg/L) but below LRL (0.1 µg/L)
 D: Result derived from a dilution of the extract
 U: Analytes reported as an isomeric pair due to insufficient baseline resolution

Table D13. Laboratory data for PAC-amended sediment slurry (VOCs – water).

Amended Sediment Slurry Test - AST - VOAs (Water)												
Sample	PAC Conc.	Dilution	Sample	TSS	Acetone	Methylene-chloride	Benzene	Toluene	Ethyl-benzene	m/p - Xylene	o - Xylene	
	mg/L			mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	
Initial Water Concentrations	Sample Det. Limit				100	5	5	5	5	5	5	
	AST-1	0.025	1:10	Total	1290	130 J	U	541	250	15	162	64.3
	AST-2	0.050	1:10	Total	1130	130 J	U	655	326	21.5	219	83.1
	AST-3	0.10	1:10	Total	1110	150 J	U	642	300	19 J	206	80.1
	AST-1	0.025	1:10	Dissolved		160 J	U	405	186	11 J	115	47.3
	AST-2	0.050	1:10	Dissolved		140 J	U	316	151	8.3 J	91.2	37.6
Final Water Concentrations	AST-3	0.10	1:10	Dissolved		130 J	U	308	145	7.9 J	86.7	35.6
	Sample Det. Limit				10	0.5	0.5	0.5	0.5	0.5	0.5	
	AST-1	0.025	1:1	Total		38.1	4.5	U	U	U	U	U
	AST-2	0.050	1:1	Total		46.6	3.1	U	U	U	U	U
	AST-3	0.10	1:1	Total		45.2	2.9	U	U	U	U	U
	AST-1	0.025	1:1	Dissolved		35.6	2.8	U	U	U	U	U
	AST-2	0.050	1:1	Dissolved		47.2	2.5	U	U	U	U	U
	AST-3	0.10	1:1	Dissolved		46.5	2.3	U	U	U	U	U

U = Undetected
 J = Estimated concentration below LRL

Table D14. Laboratory data and flux calculations for additional test (PAC-amended sediment slurry) (PAHs – traps).

Additional Test (AT) - PAH OID 08896283 Volume extract collected = 2 mL Liquid surface area = 375 cm2																	
Test	PAC Conc.	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene	
	mg/L	hr	hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr
AT	0.1	2	2	14.70	39.20	10.60	28.27	4.30	11.47	6.10	16.27	6.10	16.27	3.10	8.27	0.98	2.61
AT	0.1	6	4	8.30	11.07	16.00	21.33	6.90	9.20	16.10	21.47	15.30	20.40	10.30	13.73	5.20	6.93
AT	0.1	24	18	20.70	6.13	10.00	2.96	5.40	1.60	33.70	9.99	33.30	9.87	24.10	7.14	9.70	2.87
AT	0.1	48	24	8.50	1.89	1.60	0.36	1.20	0.27	7.30	1.62	12.50	2.78	6.80	1.51	2.70	0.60
AT	0.1	96	48	6.50	0.72	1.60	0.18	1.20	0.13	2.50	0.28	7.00	0.78	5.50	0.61	3.80	0.42
AT	0.5	2	2	19.80	52.80	5.50	14.67	2.20	5.87	2.70	7.20	2.80	7.47	1.20	3.20	0.27	0.72
AT	0.5	6	4	12.10	16.13	14.20	18.93	6.10	8.13	9.60	12.80	9.70	12.93	5.30	7.07	1.90	2.53
AT	0.5	24	18	16.80	4.98	14.60	4.33	7.50	2.22	33.60	9.96	36.40	10.79	21.30	6.31	6.00	1.78
AT	0.5	48	24	21.40	4.76	4.50	1.00	2.60	0.58	11.00	2.44	18.40	4.09	8.60	1.91	2.10	0.47
AT	0.5	96	48	11.40	1.27	3.50	0.39	2.00	0.22	5.10	0.57	12.40	1.38	7.90	0.88	2.20	0.24
AT	1.0	2	2	17.80	47.47	6.70	17.87	2.60	6.93	3.20	8.53	3.30	8.80	1.50	4.00	0.42	1.12
AT	1.0	6	4	13.60	18.13	12.00	16.00	5.00	6.67	9.30	12.40	9.90	13.20	5.30	7.07	1.90	2.53
AT	1.0	24	18	183.00	54.22	28.30	8.39	14.60	4.33	24.20	7.17	27.80	8.24	21.00	6.22	8.00	2.37
AT	1.0	48	24	19.80	4.40	4.00	0.89	2.70	0.60	8.60	1.91	14.70	3.27	9.70	2.16	2.00	0.44
AT	1.0	96	48	16.50	1.83	4.10	0.46	2.60	0.29	4.90	0.54	13.50	1.50	9.00	1.00	2.00	0.22
				mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg	
AT	Sediment concentration			970		202		91.1		68		256		275		726	

Test	PAC Conc.	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-anthracene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]-pyrene	Indeno[1,2,3-cd]-pyrene	Dibenz[<i>a,h</i>]-anthracene	Benzo[<i>g,h,i</i>]-perylene
	mg/L	hr	hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
AT	0.1	2	2	0.22	0.59	<.10	<0.27	<.10	<.27	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.1	6	4	1.60	2.13	0.24	0.32	0.11	0.15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.1	24	18	6.80	2.01	2.30	0.68	1.10	0.33	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.1	48	24	2.70	0.60	3.80	0.84	1.90	0.42	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.1	96	48	2.90	0.32	6.80	0.76	3.50	0.39	0.05J	0.04J	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.5	2	2	0.07	0.19	0.03	0.08	<.10	<.27	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.5	6	4	0.57	0.76	0.08	0.11	0.05	0.07	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.5	24	18	4.40	1.30	1.10	0.33	0.49	0.15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.5	48	24	2.50	0.56	1.70	0.38	0.74	0.16	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	0.5	96	48	2.00	0.22	2.80	0.31	1.30	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	1.0	2	2	0.11	0.29	0.04	0.11	<.10	<.27	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	1.0	6	4	0.54	0.72	0.11	0.15	0.06	0.08	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	1.0	24	18	4.20	1.24	1.10	0.33	0.48	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	1.0	48	24	3.50	0.78	1.60	0.36	0.83	0.18	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
AT	1.0	96	48	3.90	0.43	3.00	0.33	1.30	0.14	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
				mg/kg		mg/kg		mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
AT	Sediment concentration			282		506		388		193	165	114	105	149	93.2	16	82.7

Flux = PAH concentration (µg/mL) * (2 mL) * (1000 ng/µg)/(375 cm²)/(Elapsed time (hr))

Table D15. Laboratory data and flux calculations for additional test (PAC-amended sediment slurry) (VOCs – traps).

Additional Test (AT) - VOAs																	
Simulated effluent prepared using a 100 g/L TSS 3 liters of unfiltered effluent loaded into glass jars (0 head space) and PAC added to produce 3 concentrations of 0.10 mg/L, 0.50 mg/L and 1.0 mg/L Jars with effluent/PAC slurry tumbled for 15 minutes. Contents allowed to settle for 4 hours. Supernatant decanted into flux chambers Concentration in ng/tube (traps (Orbo 402, Supelco))																	
Test	PAC Conc. mg/L	Time from Start hrs	Time trap on chamber hrs	Acetone		Dimethylenechloride		Benzene		Toluene		Ethylene		m/p - Xylene		o - Xylene	
				ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr
AT - 1	0.1	0.5	0.5	< 500	<2.7	27900	149	6370	34.0	16300	86.9	2090	11.1	13200	70.4	3110	16.6
AT - 1	0.1	1	0.5	< 500	<2.7	31000	165	4250	22.7	10000	53.3	1330	7.09	8490	45.3	1990	10.6
AT - 1	0.1	2	1	< 500	<1.3	32000	85.3	1780	4.75	4370	11.7	900	2.40	6060	16.2	1650	4.40
AT - 1	0.1	4	2	< 500	<0.67	27900	37.2	400	0.533	870	1.16	230	0.307	1690	2.25	630	0.840
AT - 1	0.1	6	2	< 500	<0.67	27400	36.5	120	0.160	400	0.533	120	0.160	940	1.25	330	0.440
AT - 1	0.1	24	18	< 500	<0.07	26300	3.90	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015
AT - 1	0.1	48	24	< 500	<0.06	17100	1.90	<100	<0.011	120	0.013	<100	<0.011	<100	<0.011	<100	<0.011
AT - 1	0.1	96	48	< 500	<0.03	1500	0.08	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006
AT - 2	0.5	0.5	0.5	< 500	<2.7	37100	198	5860	31.3	15000	80.0	1890	10.1	11800	62.9	2990	15.9
AT - 2	0.5	1	0.5	< 500	<2.7	30700	164	4140	22.1	10100	53.9	1250	6.67	8180	43.6	2140	11.4
AT - 2	0.5	2	1	< 500	<1.3	38100	102	1660	4.43	4340	11.6	820	2.19	5700	15.2	1590	4.24
AT - 2	0.5	4	2	< 500	<0.67	37100	49.5	380.0	0.507	930	1.24	240	0.320	1810	2.41	650	0.867
AT - 2	0.5	6	2	< 500	<0.67	19800	26.4	110	0.147	370	0.493	100	0.133	830	1.11	300	0.400
AT - 2	0.5	24	18	< 500	<0.07	20100	2.98	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015
AT - 2	0.5	48	24	< 500	<0.06	23500	2.61	<100	<0.011	<100	<0.011	<100	<0.011	<100	<0.011	<100	<0.011
AT - 2	0.5	96	48	< 500	<0.03	27200	1.51	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006
AT - 3	1.0	0.5	0.5	< 500	<2.7	37800	202	4690	25.0	12300	65.6	1590	8.48	10100	53.9	2530	13.5
AT - 3	1.0	1	0.5	< 500	<2.7	51200	273	5660	30.2	12600	67.2	1480	7.89	9470	50.5	2450	13.1
AT - 3	1.0	2	1	< 500	<1.3	60200	161	2070	5.52	5260	14.0	940	2.51	5990	16.0	1710	4.56
AT - 3	1.0	4	2	< 500	<0.67	38800	51.7	640	0.853	1510	2.01	390	0.520	2860	3.81	1010	1.35
AT - 3	1.0	6	2	< 500	<0.67	46400	61.9	260	0.347	660	0.880	180	0.240	1300	1.73	460	0.613
AT - 3	1.0	24	18	< 500	<0.07	29600	4.39	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015	<100	<0.015
AT - 3	1.0	48	24	< 500	<0.06	25500	2.83	<100	<0.011	120	0.0133	<100	<0.011	<100	<0.011	<100	<0.011
AT - 3	1.0	96	48	< 500	<0.03	37800	2.10	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006	<100	<0.006
AT	Sediment concentration			µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg	
AT	Sediment concentration			<10000		<500		6260		7540		960 J		10600		3360	

Flux = VOA concentration (ng/tube)/(375 cm²)/(Elapsed time (hr))

Table D16. Laboratory data for additional test (PAC-amended sediment slurry) (PAHs – water).

Additional Test (AT) - PAHs (Water)												
Sample	PAC Conc. mg/L	Sample	Napthalene µg/L	1-Methyl-napthalene µg/L	2-Methyl-napthalene µg/L	Ace-napthylene µg/L	Acenaphthene µg/L	Fluorene µg/L	Phenanthrene µg/L	Anthracene µg/L	Fluoranthene µg/L	
Final Water Concentration	AT-1	0.1	Total	14.2	0.83	1.91	2.19	2.35	2.87	9.54	8.02	47.3
	AT-2	0.5	Total	20.8	1.26	2.81	2.69	3.31	4.02	11.3	8.47	41.8
	AT-3	1.0	Total	18	1.35	2.38	2.4	3.04	3.87	8.53	8.27	34.7
	AT-1	0.1	Dissolved	0.12	<0.20	0.04J	0.1	0.25	0.24	0.1	1.35	11.4
	AT-2	0.5	Dissolved	0.08J	<0.20	0.020	0.11	0.19	0.14	0.08J	1.02	10.4
	AT-3	1.0	Dissolved	0.13	<0.20	0.05J	0.22	0.57	0.67	0.1	2.31	8.63
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
AT			Sediment concentration	970	202	91.1	68	256	275	726	282	506
Sample	PAC Conc. mg/L	Sample	Pyrene µg/L	Benzo(a)-anthracene µg/L	Chrysene µg/L	Benzo(b)-fluoranthene µg/L	Benzo(k)-fluoranthene µg/L	Benzo(a)-pyrene µg/L	Indeno(1,2,3-cd)pyrene µg/L	Dibenzo(ah)-anthracene µg/L	Benzo(ghi)-perylene µg/L	
Final Water Concentration	AT-1	0.1	Total	32	16.8	15.1	9.68	10.3	13.4	8.51	1.46	7.81
	AT-2	0.5	Total	32.3	16.2	15.2	10.3	9.75	13.4	10	1.73	9.12
	AT-3	1.0	Total	25.6	12.2	10.7	6.52	6.56	8.49	5.84	1.05	5.32
	AT-1	0.1	Dissolved	6.35	1.08	0.74	0.21	0.24	0.27	0.09J	<0.20	0.09J
	AT-2	0.5	Dissolved	5.45	0.93	0.62	0.19	0.19	0.24	0.08J	<0.20	0.06J
	AT-3	1.0	Dissolved	4.57	0.72	0.49	0.13	0.15	0.17	0.07J	<0.20	0.06J
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
AT			Sediment concentration	388	193	165	114	105	149	93.2	16	82.7

J: Estimated concentration above MDL but below LRL

Additional Test (AT) - VOAs (Water)												
Sample		PAC Conc.			TSS	Acetone	Methylene-chloride	Benzene	Toluene	Ethyl-benzene	m/p - Xylene	o - Xylene
		mg/L	Dilution	Sample	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Initial Water (Elutriate)												
	AT		1:5			120 J	8.4 J	161	111	7.6 J	51.7	21.2
Final Water												
	AT-1	0.1	1:1	Total	NA	66.8	2.0 J	<0.5	<0.5	<0.5	<0.5	<0.5
	AT-2	0.5	1:1	Total	NA	65.1	2.8	<0.5	<0.5	<0.5	<0.5	<0.5
	AT-3	1.0	1:1	Total	NA	57.9	1.7 J	<0.5	<0.5	<0.5	<0.5	<0.5
	AT-1	0.1	1:1	Dissolved		53.6	1.9 J	<0.5	<0.5	<0.5	<0.5	<0.5
	AT-2	0.5	1:1	Dissolved		93.1	2.4	<0.5	<0.5	<0.5	<0.5	<0.5
	AT-3	1.0	1:1	Dissolved		97.4	1.9 J	<0.5	<0.5	<0.5	<0.5	<0.5

U = Undetected

J = Estimated concentration below I RL

Resuspension Chamber Test (RCT)																	
OID 08896286 Volume extract collected = 2 mL Liquid surface area = 2500 cm ²																	
Test	TSS*	Time from Start	Elapsed Time	Naphthalene		2-Methylnaphthalene		1-Methylnaphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene	
	mg/L	hr	hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr
RCT (Settling)		2	2	1390	709	123	65.6	45	24.0	10.7	5.71	35.1	18.7	13.7	7.31	5.00	2.67
RCT (Settling)		6	4	3150	630	356	71.2	148	29.6	32.1	6.42	121	24.2	42.2	8.44	16.7	3.34
RCT (Settling)	1240	10	4	2360	472	274	54.8	113	22.6	27.6	5.52	100	20.0	36.0	7.20	14.7	2.94
RCT (Mixing)	1370	2	2	1580	632	110	44.0	44.9	18.0	8.60	3.44	33.7	13.5	12.1	4.84	4.70	1.88
RCT (Mixing)	1670	4	2	2040	816	78	31.3	32.5	13.0	17.3	6.92	57.0	22.8	19.9	7.96	7.80	3.12
RCT (Mixing)	1600	15	11	8920	476	1100	58.7	444	23.7	119	6.35	405	21.6	147	7.84	52.2	2.78
RCT (Mixing)	560	48	33	5200	203	1390	54.2	537	21.0	190	7.41	723	28.2	296	11.6	120	4.68
RCT (Mixing)	340	72	24	3490	116	677	22.6	290	9.67	139	4.63	526	17.5	249	8.30	112	3.73
RCT (Mixing)	240	96	24	2520	84.0	590	19.7	265	8.83	177	5.90	684	22.8	395	13.2	198	6.60
RCT (Mixing)	290	144	48	624	10.4	297	4.95	212	3.53	181	3.02	825	13.8	476	7.93	223	3.72
				mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg		mg/kg	
RCT	Sediment concentration			1570		270		118		61.2		354		332		925	
Test	TSS*	Time from Start	Elapsed Time	Anthracene		Fluoranthene		Pyrene		Benzo[a]-fluoranthene	Chrysene	Benzo[b]-fluoranthene	Benzo[k]-fluoranthene	Benzo[a]-pyrene	Indeno[1,2,3-cd]-pyrene	Dibenz[a,h]-anthracene	Benzo[ghi]perylene
	mg/L	hr	hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	ng/cm2/hr	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
RCT (Settling)		2	2	1.40	0.75	0.18	0.096	0.0800	0.0427	<0.10		<0.10		<0.10	<0.10	<0.10	<0.10
RCT (Settling)		6	4	5.00	1.00	0.78	0.156	0.340	0.068	<0.10		<0.10		<0.10	<0.10	<0.10	<0.10
RCT (Settling)	1240	10	4	4.20	0.84	0.63	0.126	0.250	0.050	<0.10		<0.10		<0.10	<0.10	<0.10	<0.10
RCT (Mixing)	1370	2	2	1.30	0.52	0.20	0.080	0.330	0.132	<0.10		<0.10		0.03J	<0.10	0.04J	<0.10
RCT (Mixing)	1670	4	2	2.20	0.88	0.38	0.152	0.170	0.0680	0.03J		0.05J		0.03J	0.03J	0.03J	<0.10
RCT (Mixing)	1600	15	11	13.1	0.70	1.80	0.096	1.00	0.0533	0.160	0.0640	0.150	0.0600	<0.10	<0.10	<0.10	<0.10
RCT (Mixing)	560	48	33	36.8	1.44	6.50	0.254	2.50	0.0976	<0.10		<0.10		<0.10	<0.10	<0.10	<0.10
RCT (Mixing)	340	72															

Table D19. Laboratory data and flux calculations for resuspension chamber test (VOCs – traps).

Resuspension Chamber Test (RCT) - VOAs																	
OID 08896286 - Traps																	
Liquid surface area = 2500 cm ²																	
10 Hrs settling followed by 144 hrs mixing																	
Started oscillation in upper 30% of water column after 10 hour settling time																	
Test	TSS	Time from Start	Elapsed Time	Acetone		Methylene Chloride		Benzene		Toluene		Ethylbenzene		m,p - Xylene		o - Xylene	
	mg/L	hrs	hrs	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr	ng/tube	ng/cm ² /hr
RCT (Settling)	NA*	1	1	<5000	<2.0	290000	116	2480	0.992	13800	5.52	8100	3.24	94200	37.7	26100	10.4
RCT (Settling)	NA	2	1	<5000	<2.0	25000	10.0	1310	0.524	7720	3.09	4460	1.78	50600	20.2	14200	5.68
RCT (Settling)	NA	6	4	<5000	<0.50	1360000	136	<1000	<0.10	1940	0.19	1170	0.117	11100	1.11	3540	0.354
RCT (Settling)	NA	10	4	<5000	<0.50	876000	87.6	1110	0.111	3780	0.378	1490	0.149	13120	1.31	3320	0.332
RCT (Mixing)	NA	0.5	0.5	<5000	<4.0	920000	736	36200	29.0	97000	77.6	15200	12.2	146000	117	34000	27.2
RCT (Mixing)	NA	2	1.5	<5000	<1.3	812000	217	10300	2.75	26200	6.99	7260	1.94	75200	20.1	21500	5.73
RCT (Mixing)	NA	4	2	<5000	<1.0	388000	77.6	10300	2.06	20800	4.16	4940	0.988	52500	10.5	16700	3.34
RCT (Mixing)	NA	15	11	<5000	<0.18	138000	3.68	1780	0.047	10100	0.269	1840	0.049	18020	0.481	6580	0.175
RCT (Mixing)	NA	48	33	<5000	<0.061	33000	0.55	1770	0.030	5860	0.098	<1000	<0.012	8760	0.146	2560	0.043
RCT (Mixing)	NA	72	24	<5000	<0.083	1050000	17.5	<1000	<0.017	3360	0.056	<1000	<0.017	4040	0.067	<1000	<0.017
RCT (Mixing)	NA	96	24	<5000	<0.083	1020000	17.0	<1000	<0.017	2140	0.036	<1000	<0.017	3240	0.054	<1000	<0.017
RCT (Mixing)	NA	144	48	<5000	<0.042	31200	0.26	<1000	<0.008	1880	0.016	<1000	<0.008	2560	0.021	<1000	<0.017
				µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg		µg/kg	
RCT	Sediment concentration			<8000		<400		5240		8280		1500 J		15600		4880	
				Sampling complete on 9/26 (double checked TSS on 9/29 (at 260 mg/L) No Suspended Solids or Analytical for the waters during the settling period. Samples taken after 10 hour settling period prior to start of oscillation													

Table D20. Laboratory data and flux calculations for resuspension chamber test (PAHs – water).

Resuspension Chamber Test (RCT) - PAHs (Water)											
OID 08896291 Liquid surface area = 2500 cm ² 10 Hrs settling followed by 144 hrs mixing											
Test	Type Sample	Time from Filling/ Mixing	Napthalene	1-Methyl-napthalene	2-Methyl-napthalene	Ace-naphylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene
		hrs	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
RCT (Settling)	Total	0	42000	8380	3825	7280	8090	13000	37400	13100	26300
RCT (Settling)	Total	10	1150	82.7	41.8	30.3	103	89.3	229	65.2	147
RCT (Mixing)	Total	2	1170	107	51.5	38.1	146	136	374	113	246
RCT (Mixing)	Total	4	1010	90.6	42.8	34.3	134	128	374	110	243
RCT (Mixing)	Total	15	12600	2460	11120	747	3540	3650	10900	3510	7670
RCT (Mixing)	Total	48	396	42	22.3	26.5	86.9	83.9	215	63.1	141
RCT (Mixing)	Total	72	113	19.9	13.3	19.3	68.1	67	154	52	114
RCT (Mixing)	Total	96	4.9	4.6	7.6	15.6	67.4	73.2	165	67.5	157
RCT (Mixing)	Total	144	2.8	0.75	1.7	5.9	45.9	30.3	7.9	46.6	169
RCT (Settling)	Dissolved	0	730	41.4	21.2	59.2	29.4	35.9	54.6	17.4	14.8
RCT (Settling)	Dissolved	10	486	22.3	12.2	20.1	24.5	22.1	39.4	12.7	13.9
RCT (Mixing)	Dissolved	2	563	32.9	17.1	24.3	38.9	37.5	65.3	19.8	25
RCT (Mixing)	Dissolved	4	414	23.5	12.3	19.6	30.1	30.6	52	16.4	17.5
RCT (Mixing)	Dissolved	15	545	29.9	15.9	16.8	37.9	31.2	49.6	15.2	18.2
RCT (Mixing)	Dissolved	48	212	14.4	8	12.3	29.7	27.7	43	12.3	17.9
RCT (Mixing)	Dissolved	72	112	10.1	6.1	13.4	29.7	30.4	55.1	17.6	23.6
RCT (Mixing)	Dissolved	96	1.6	2.5	3.8	10	31.9	38.9	66.4	31	59
RCT (Mixing)	Dissolved	144	0.59	0.3	0.85	4	16.1	11.9	9.8	4.9	17.2
Test	Type Sample	Time from Filling/ Mixing	Pyrene	Benzo(a)-anthracene	Chrysene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Benzo(a)-pyrene	Indeno(1,2,3-cd)pyrene	Dibenzo(ah)-anthracene	Benzo(ghi)-perylene
		hrs	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
RCT (Settling)	Total	0	18300	8390	8230	5010	5380	6630	3760	747	3560
RCT (Settling)	Total	10	94.6	38.6	29.5	18.8	20.3	25.9	11.9	3.2	9.9
RCT (Mixing)	Total	2	176	74.8	62.6	41.7	44.9	52.5	23.3	6	19.3
RCT (Mixing)	Total	4	168	69.3	58.3	34.8	35.7	47	22.9	5.8	18.8
RCT (Mixing)	Total	15	4280	2230	1710	1110	1100	1460	726	182	605
RCT (Mixing)	Total	48	94.6	39.6	29.6	17.8	20	25.3	11.3	2.8	9.2
RCT (Mixing)	Total	72	69.1	32.8	24.4	14.7	16.5	20.6	9.2	2.3	7.5
RCT (Mixing)	Total	96	93.1	45.6	32.4	20.1	22.2	28.2	12.3	3.2	9.9
RCT (Mixing)	Total	144	101	48.3	33.6	22.3	21.8	28.5	12.7	3.5	10.3
RCT (Settling)	Dissolved	0	7.1	1.8	1.2	0.53	0.54	0.71	0.31	0.09J	0.26
RCT (Settling)	Dissolved	10	7.8	2.7	2.1	0.94	1.1	1.3	0.55	0.17	0.44
RCT (Mixing)	Dissolved	2	115.7	5.4	3.9	2	2.3	2.9	1.3	0.37	1.1
RCT (Mixing)	Dissolved	4	12.2	4.1	3.1	1.6	1.7	2.2	1	0.26	0.8
RCT (Mixing)	Dissolved	15	11.7	4.2	3.2	1.7	1.8	2.3	1	0.28	0.77
RCT (Mixing)	Dissolved	48	10.9	4.2	3.2	1.8	1.8	2.3	1.1	0.33	0.88
RCT (Mixing)	Dissolved	72	14.3	6.2	4.3	2.4	2.8	3.5	1.5	0.38	1.2
RCT (Mixing)	Dissolved	96	34.2	16.5	11.7	7.1	7.5	9.8	4.3	1.2	3.4
RCT (Mixing)	Dissolved	144	11	3.3	2.2	1	1.1	1.4	0.58	0.17	0.45

Table D21. Laboratory data and flux calculations for resuspension chamber test (VOCs – water).

Resuspension Chamber Test (RCT) - VOAs (Water)									
OID 08896291 Liquid surface area = 2500 cm ² 10 Hrs settling followed by 144 hrs mixing Started oscillation in upper 30% of water column after 10 hour settling time									
Test	Type Sample	Time from Filling/ Mixing hrs	Acetone µg/L	Methylene Chloride µg/L	Benzene µg/L	Toluene µg/L	Ethyl-benzene µg/L	m,p - Xylene µg/L	o - Xylene µg/L
RCT (Settling)	Total	0	<100	<5	480	367	26.4	267	99.4
RCT (Settling)	Total	10	160 J	<5	518	292	18 J	194	76.2
RCT (Mixing)	Total	0.5	150 J	6.6 J	413	259	19 J	212	82.8
RCT (Mixing)	Total	2	120 J	<5	420	281	19 J	204	75.7
RCT (Mixing)	Total	4	130 J	<5	412	268	18 J	197	73.6
RCT (Mixing)	Total	15	110 J	<5	225	153	10 J	110	41.1
RCT (Mixing)	Total	48	130 J	<5	47	39.1	<5	30.7	12 J
RCT (Mixing)	Total	72	180 J	<5	<5	7.4 J		7.0 J	<5
RCT (Mixing)	Total	96	120 J	<5	<5	6.9J	<5	<5	<5
RCT (Mixing)	Total	144	110 J	<5	<5	7.8 J	<5	<5	<5
RCT (Settling)	Dissolved	0	<100	16 J	91.5	61	<5	41.4	17 J
RCT (Settling)	Dissolved	10	127	3.7 J	157	83.5	4.2 J	46.7	22.3
RCT (Mixing)	Dissolved	0.5	81 J	3.7 J	101	49.5	<3	23.5	10.8
RCT (Mixing)	Dissolved	2	78 J	<3	114	70	3.9 J	41.4	17.6
RCT (Mixing)	Dissolved	4	74 J	<3	74.2	40.8	<3	24.8	10.6
RCT (Mixing)	Dissolved	15	95 J	<3	64.1	34.3	<3	20.2	9.0 J
RCT (Mixing)	Dissolved	48	110 J	<3	9.9 J	9.0 J	<3	7.2 J	3.0 J
RCT (Mixing)	Dissolved	72	100 J	3.9 J	<3	<3	<3	<3	<3
RCT (Mixing)	Dissolved	96	110 J	6.1 J	<3	<3	<3	<3	<3
RCT (Mixing)	Dissolved	144	77 J	5.3 J	<3	<3	<3	<3	<3
			µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
	Sediment		<8000	<400	5240	8280	1500 J	15600	4880

Table D22. Laboratory data for dust and sediment collected from wind tunnel experiments (PAHs).

Wind Tunnel - PAHs																			
OID 08877123																			
Extracts for particles separated by density																			
Surface samples - surface dust collected and separated																			
PAC Amended - material removed through depth from the wind tunnel,																			
mixed and separated																			
Unamended - IHC sediment not amended with PAC																			
Concentrations not corrected for 3-mL extract volume																			
	TOC	Naphtha- lene	2-Methyl- naphtha- lene	1-Methyl- naphtha- lene	Acenaph- thylene	Acenaph- thene	Fluorene	Phenanth- rene	Anthra- cene	Fluoran- thene	Pyrene	Benzo[a]- naphtha- cene	Chrysene	Benzo[b]- fluoran- thene	Benzo[k]- fluoran- thene	Benzo[a]- pyrene	Indeno- [1,2,3-cd]- pyrene	Dibenzo- [a,h]anthra- cene	Benzo- [g,h,i]- perylene
	%	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Surface Floats-1	17.3	6.28	1.29	0.5	1.3	1.37	3.4	15.78	4.83	17.92	10.54	6	4.78	3.01	2.57	2.49	2.27	0.5	1.51
Surface Floats-2	18.9	5.66	1.16	0.45	1.04	1.17	2.88	13.25	4.12	13.29	9.57	4.98	4.04	2.41	2.2	2.04	1.87	0.42	1.26
Surface Floats-3	16.9	4.52	0.98	0.38	0.84	1	2.45	11.69	3.62	11.76	8.38	4.39	3.59	2.12	1.89	1.76	1.69	0.37	1.12
Surface Sinks-1		15.28	3.23	1.38	3.5	4.11	9.37	40.26	13.14	43.05	28.95	16.53	14.05	8.68	7.83	8.43	7.85	1.69	5.12
Surface Sinks-2		15.51	3.27	1.37	3.6	4.23	9.65	41.58	13.46	44.11	31.13	17.16	14.38	8.98	8.22	8.95	8.08	1.73	5.22
Surface Sinks-3		18.46	3.64	1.52	4.38	4.48	10.57	44.47	14.16	49.91	31.88	18.22	14.95	9.91	8.47	9.51	8.97	1.91	5.77
PAC Amend Floats-1	16.3	6.56	1.49	0.56	1.28	1.41	4.09	18.17	6.22	15.76	10.23	5.84	4.26	2.53	2.18	2.82	2.02	0.46	1.33
PAC Amend Floats-2	21.0	5.38	1.26	0.47	1.16	1.25	3.86	17.06	5.45	14.8	9.78	5.7	4.05	2.4	2.26	2.77	1.97	0.45	1.33
PAC Amend Floats-3	16.3	6.06	1.39	0.53	1.31	1.28	3.79	17	5.78	14.93	8.79	5.4	3.97	2.38	2.07	2.64	1.92	0.45	1.3
PAC Amend Sinks-1		17.73	4.05	1.68	5.86	5.11	13.81	54.29	18.31	44.78	30.11	19.3	15.08	9.9	8.46	11.67	9.35	2.06	6.09
PAC Amend Sinks-2		15.52	3.43	1.42	4.72	5.16	12.88	54.66	18.44	49.95	30.44	20.63	15.67	10.04	9.05	11.99	9.31	2.05	5.95
PAC Amend Sinks-3		23.99	4.69	2.04	8.78	5.5	15.41	63.22	22.98	65.99	43.31	30.92	22.89	16.87	13.69	20.48	16.1	3.38	10.08
Unamended Floats-1	16.5	2.42	0.82	0.23	0.32	1.13	3.34	12.96	4.06	10.15	7.49	4.26	3.22	1.6	1.78	2.26	1.7	0.27	1.05
Unamended Floats-2	16.5	3.09	0.98	0.27	0.39	1.46	3.91	15.18	4.92	11.62	9.2	5.15	3.81	2.14	2.23	2.86	2.22	0.38	1.38
Unamended Floats-3	17.1	4.21	1.22	0.33	0.71	2.02	5.29	19.41	6.52	16.99	10.4	6.77	5.07	3.15	2.71	4.04	3.24	0.54	1.95
Unamended Sinks-1		15.5	5.78	2.26	4.55	18.8	29.29	80.38	28.52	63.72	49.81	27.98	20.51	12.03	12.38	16.81	13.2	2.37	7.88
Unamended Sinks-2		14.8	5.7	2.29	4.51	18.4	27.58	80.28	27.73	65.07	47	27.41	20.68	12.8	11.32	16.89	13.03	2.5	7.71
Unamended Sinks-3		14.7	5.59	2.18	4.46	17.51	26.4	78.29	26.61	61.96	41.34	26.77	19.85	11.86	11.36	16.39	12.55	2.41	7.37

Table D23. Laboratory data for particulate losses from wind tunnel experiments.

Date	Conditions	Wind Speed	Replicate No.			
			1	2	3	4
	Background	No wind*	0.100	0.064	0.075	
	Background	10 mph**	0.130	0.114	0.116	
23-Jan-2007		10 mph	0.125	0.101	0.115	
27-Feb-2007		10 mph	0.124	0.094	0.115	
6-Mar-2007		10 mph	0.156	0.149	0.192	0.236
18-Apr-2007		7 mph	0.101	0.109	0.115	
20-Mar-2007		5 mph	0.106	0.103	0.0412	0.0853
12-Apr-2007		2.5 mph	0.0719	0.0854	0.0888	

* Background (No Wind) = TSP collector operating without any air being pull across sediment surface
** Background = Blower operating at a speed to produce an average of 10 mph in the tunnel

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14. ABSTRACT Volatilization controls have been considered to meet limits on volatile emissions that may be imposed on dredging, disposal, and site management of an Indiana Harbor and Canal (IHC) Confined Disposal Facility (CDF). Carbon adsorption is a proven technology for removal and sequestration of organic compounds in water, but its application to control volatile emissions from dredging operations has not been thoroughly investigated. This study investigated the processes relevant to volatile emission control, including the forms of activated carbon to use, application rates, and application methods appropriate for IHC CDF. Based on settling tests, a regenerated carbon, which can be used at about one-half the cost of virgin activated carbon, was selected for the study. The adsorption isotherm data showed that carbon adsorption was very effective for the removal of three- and higher-ring polynuclear aromatic hydrocarbons (PAHs) from water. Column settling tests showed that powdered activated carbon addition to dredged material slurries either enhanced settling or had no effect. Carbon treatment of dredged material slurry, dredged material ponded water, and exposed dredged material solids effectively reduced volatilization of lower molecular weight PAHs in laboratory studies. Carbon treatment appeared to have little effect on reducing volatilization of higher molecular weight PAHs and volatile organic compounds.					
15. SUBJECT TERMS		Confined disposal facilities		Polynuclear aromatic hydrocarbons (PAHs)	
Activated carbon		Dredging		Volatile emissions	
Carbon adsorption		Indiana Harbor		Volatile organic compounds (VOC)	
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